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# EFFECT ON THE PERFORMANCE OF A TURBOSUPERCHARGED ENGINE OF AN EXHAUST-GAS-TO-AIR HEAT EXCHANGER FOR THERMAL ICE PREVENTION

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WASHINGTON

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Service Command, U.S. Army Air Forces

# EFFECT ON THE PERFORMANCE OF A TURBOSUPERCHARGED ENGINE OF AN EXHAUST-GAS-TO-AIR HEAT EXCHANGER FOR THERMAL ICE PREVENTION

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## SUMMARY

This report presents the results of a flight investigation to determine the effect on the performance of a turbosupercharged engine of an exhaust-gas-to-air heat exchanger installed between the engine-exhaust collector ring and the turbosupercharger. The operating characteristics of the turbosupercharger and the engine were obtained for various engine speeds from 1400 to 2300 rpm during level flight at 10,000, 17,000, and 24,000 feet pressure altitudes with the standard exhaust stack installed and with the heat exchanger in place. The effect of the heat exchanger on the turbosupercharged-engine performance is shown by a comparison of the data obtained for the two installations.

A summary of the test data is presented in tabular form, and the change in operating characteristics of the engine and turbosupercharger caused by the heat-exchanger installation

is shown on curves prepared from the test data. The heat-exchanger installation caused an increase of engine back pressure and an increase of the turbosupercharger waste-gate-valve closure to attain a given engine manifold pressure. These changes, however, did not affect the range of engine powers attainable for normal operation of the test airplane at the three test altitudes. The increase of engine back pressure represented a maximum decrease of engine power of less than 1 percent. Loss of engine power due to the effect of the heat exchanger on the turbosupercharger operation was found to occur only below an engine speed of 1800 rpm and at engine-power conditions beyond the range of normal operation at these speeds.

## INTRODUCTION

The thermal ice-prevention systems developed for the B-24D and B-17F airplanes, which are described in references 1 and 2, respectively, utilize exhaust-gas-to-air heat exchangers to transfer heat from the exhaust gas to the air to be circulated through the ice-prevention system. The heat exchangers are located in the exhaust systems between the engine-exhaust collector rings and the turbosuperchargers. The removal of heat from the exhaust gas by the heat exchanger causes a decrease of the gas temperature and, thereby, a decrease in the energy of the gas flowing to the turbine which drives the turbo-supercharger. In order to obtain the same engine power that

was obtained with the standard exhaust stack in place, which will require essentially the same supercharging, a greater quantity of exhaust gas must flow through the turbine wheel when the heat exchanger is installed because the energy per pound of gas has been decreased. The increase in the quantity of exhaust passing through the turbine wheel necessitates an increased pressure at the turbine nozzle box which will be reflected as an increase in engine back pressure. The maximum amount of supercharging available is obtained when all the exhaust gas is flowing through the turbine and, because of decreased gas energy, will be less when the heat exchanger is installed than when the standard exhaust stack is used. The removal of energy from the exhaust gas by the heat exchanger will, therefore, effect the power-plant performance by increasing the engine back pressure and decreasing the maximum power obtainable with maximum supercharging. An additional increase in engine back pressure will be caused by the pressure losses across the heat exchanger.

The condition of maximum supercharging was not obtained for normal operation of the test airplane with the standard exhaust stack in place because the energy available in the gas exceeded that required for supercharging. However, a limited amount of data obtained during tests of several heat exchangers on the test airplane (reference 3) indicated that the amount of energy removed from the exhaust gas by the heat exchangers might be large enough to cause the condition of

maximum supercharging available to occur at engine powers below the maximum for normal engine operation.

This investigation was conducted to determine if a heat exchanger, suitable for use in the thermal ice-prevention system, affected the performance of the turbosupercharger-engine combination of the test airplane sufficiently to decrease the range of engine powers available for normal operation. The method employed was to determine the operating characteristics of one of the outboard engines and turbosuperchargers of the test airplane with the standard exhaust stack in place during level flight at several altitudes for comparison with the operation at the same test conditions with a heat exchanger installed. The performance characteristics of the heat exchanger were also obtained in order to determine its suitability for the ice-prevention system and because the magnitude of the effect on the turbosupercharger-engine operation is directly associated with the quantity of heat removed from the exhaust gas and the pressure drop across the gas side of the heat exchanger. The energy available in the exhaust gas to drive the turbosupercharger and the quantity of exhaust gas flowing through the turbine were evaluated for both test installations in order to provide a direct indication of the effect of the heat exchanger on the turbosupercharger operation which may be correlated with the heat-exchanger performance. The engine speed, the engine manifold pressure, the turbosupercharger speed, and the turbosupercharger waste-gate

valve position which controls the amount of exhaust gas flowing through the turbine, were related to the engine brake horsepower for the various test conditions with and without the heat exchanger installed. This information shows the effect of the heat exchanger on the general operating characteristics of the power plant and on the maximum power available at various operating conditions.

The reported tests were conducted at the Ames Aeronautical Laboratory of the National Advisory Committee for Aeronautics, Moffett Field, Calif.

## EQUIPMENT

The test vehicle used in this investigation was the B-17F airplane shown in figure 1. Airplane and engine data (taken from reference 4) are as follows:

Airplane

Over-all wing span. . . . . . . . . . . . . . 103 ft 9.38 in.

Over-all length . . . . . . . . . . . . . . 74 ft 8.90 in.

Total wing area (including ailerons and flaps). . . . . . . . . . . . 1277.5 sq ft

Total weight as tested. . . . . . . . . . . . . 46,000 lb

Engine

Model . . . . . . . . . . . . . . . . . . . . R-1820-97

Type. . . . . . . . . . . . . . . .Single-row, static-radial, air-cooled

Number of cylinders . . . . . . . . . . . . . . . .Nine

| | |
|---|---|
| Bore. . . . . . . . . . . . . . . . . . . . . . . | 6.125 in. |
| Stroke. . . . . . . . . . . . . . . . . . . . . . | 6.875 in. |
| Piston displacement . . . . . . . . . . . . . . . | 1823 cu in. |
| Compression ratio . . . . . . . . . . . . . . . . | 6.70:1 |
| Blower gear ratio . . . . . . . . . . . . . . . . | 6.00:1 |
| Rated power at sea level and at 25,000 ft . . . . . . . . . . . . . | 1000 bhp at 2300 rpm |
| Take-off power. . . . . . . . . . . . . . | 1200 bhp at 2500 rpm |
| Propeller reduction gear ratio. . . . . . . . . . . . . . | 16:9 |
| Carburetor. . . . . . . . . . . . . . . . . . . . . | PD12H2 |
| Exhaust-driven turbosupercharger . . . . . . . . . . | Type B-2 |
| Maximum operating turbo-supercharger speed . . . . . . . . . . . . . | 21,300 rpm |
| Emergency rating. . . . . . . . . . . . . . . . . . | 22,400 rpm |

The airplane used for these tests was previously equipped with a thermal ice-prevention system and was used for the heat-exchanger tests reported in reference 3. For the current tests a heat exchanger was installed in nacelle 4. Engines 1 and 3 were equipped with the standard straight exhaust stacks and engine 2 with the standard glycol boiler unit for cabin heating.

Details of the plate-type heat exchanger used for the tests are shown in figure 2, and photographic views of the gas and air passages, respectively, are presented as figures 3 and 4. The heat-exchanger unit was designed to replace the removable portion of the straight stack between the exhaust collector ring and the turbosupercharger of engine 4. The installation

details of the heat exchanger are shown in figures 5 and 6. For this test installation the heated air provided by the heat exchanger was not directed into the ice-prevention system in the airplane but was ducted through the nacelle and discharged as shown in figures 5 and 6. The heat-exchanger installation ready for flight is shown in figure 7. In figure 7 the ducting which is shown suspended beneath the wing, aft of the turbosupercharger, was installed for the purpose of metering the exhaust flow through the turbosupercharger waste gate. A schematic diagram of the engine-induction and exhaust systems is presented in figure 8.

Instrumentation was provided to obtain all information required to determine (1) the flight condition, (2) the performance of the heat exchanger with regard to satisfying the requirements of the ice-prevention system, (3) the increase of engine back pressure and the decrease of the energy available in the exhaust gas to drive the turbosupercharger which were caused by the heat exchanger, (4) the power output of the engine, and (5) the operation of the turbosupercharger. The information obtained is listed here with reference to the notation used in figure 8 to indicate the location at which the various factors were measured.

General

1. Pressure altitude ($P_a$)
2. Atmospheric temperature ($T_a$)
3. Indicated airspeed

4. Engine speed

5. Turbosupercharger speed

6. Turbosupercharger waste-gate-valve position

7. Engine air-flow rate ($W_c$)

8. Engine fuel-flow rate

9. Exhaust-gas-flow rate through turbosupercharger waste gate $\left(W_{e_3}\right)$

10. Air-flow rate through heat exchanger ($W_h$)

Pressures

11. Engine manifold ($P_m$)

12. Total at carburetor inlet ($H_c$)

13. Static in carburetor boost venturi ($P_c$)

14. Static and total immediately aft of exhaust-gas collector ring $\left(P_{e_1},\ \text{and}\ H_{e_1},\ \text{respectively}\right)$

15. Total at entrance to turbosupercharger nozzle box $\left(H_{e_2}\right)$

Temperatures

16. Carburetor air ($T_c$)

17. Exhaust gas in stack immediately aft of collector ring $\left(T_{e_1}\right)$

18. Exhaust gas at nozzle-box entrance $\left(T_{e_2}\right)$

19. Exhaust gas in extension duct connected to waste gate $\left(T_{e_3}\right)$

20. Air in heat-exchange-outlet duct ($T_h$)

The instrumentation of the heat-exchanger installation is shown in figures 5 and 6. Details of the total-pressure tubes

used in the exhaust system and of the air-temperature survey used in the heat-exchanger-air outlet are given in figures 5 and 6, respectively. Total-pressure-tube surveys were installed in the standard exhaust stack in the same locations as shown for the heat exchanger. A thermocouple survey similar to that in the heat-exchanger outlet, but consisting of three instead of five thermocouples, was installed at the carburetor inlet. The type of quadruple-shielded thermocouples used to obtain the exhaust-gas temperatures is shown in figure 9. Iron-constantan thermocouple wire was used for the air thermocouples and chromel-alumel wire for the exhaust-gas thermocouples.

The air-flow rate through the heat exchanger was obtained with a venturi meter installed in the heated-air-outlet duct, as shown in figures 5, 6, and 8. The exhaust-gas-flow rate through the turbosupercharger waste gate was determined with a venturi meter installed in the duct extension shown in figures 7 and 8. Engine 4 carburetor was calibrated to obtain the engine-air and fuel-flow rates. The carburetor-impact and boost-venturi-suction pressures and the inlet-air temperature were recorded for this purpose. The impact pressure was measured in the annulus around the carburetor body into which all the impact tubes are manifolded and the suction pressure was measured at the suction side of the air-metering diaphragm. All recorded pressures, except the engine manifold pressure, were referred to the atmospheric pressure indicated at the static orifices in the service airspeed head corrected

for position error.

A resistance bulb thermometer was installed on a 12-inch mast under the nose of the fuselage for the atmospheric-air-temperature measurement. This resistance-bulb-thermometer installation was calibrated in flight to determine the error in indicated temperature caused by adiabatic heating. All temperatures were recorded with a multiple-channel simultaneous temperature recorder. The remainder of the test data was recorded with standard NACA instruments. The installation of this equipment in the airplane is shown in figures 10 and 11.

## TESTS

All test data were obtained during level flights at about 10,000, 17,000, and 24,000 feet pressure altitudes with the heat exchanger installed, and then with the standard exhaust stack installed in nacelle 4. Engine 4 was operated at each altitude at full throttle with intercooler shutters fully open over the engine-speed range of from 1400 to 2300 rpm in about 100-rpm steps. At each speed the turbosupercharger-control setting was varied from zero to full boost, or until the engine manifold pressure reached a safe maximum for the particular engine speed. All data were recorded for several different manifold pressures at each engine speed. The carburetor-mixture control was set at automatic rich for all powers at an engine speed of 2300 rpm and for the highest powers at the other speeds, and automatic lean was used for

the remainder of the operating conditions. During the flights at each altitude the indicated airspeed was maintained approximately constant at 150 miles per hour by varying the power of engines 1, 2, and 3.

## RESULTS

Summaries of the test data obtained for both the standard-exhaust-stack and heat-exchanger installations in nacelle 4 are presented in tables I and II, respectively. The values of atmospheric temperature given in the tables have been corrected for adiabatic heating. At the test airspeeds these corrections were found to be $-5^\circ$ F, $-7^\circ$ F, and $-9^\circ$ F for 10,000, 17,000, and 24,000 feet pressure altitudes, respectively.

The values of engine back pressure given in the tables are the static pressures measured immediately aft of the exhaust collector ring. The arithmetical average of the temperatures indicated by the three thermocouples in the carburetor-air inlet duct is presented as the carburetor-air temperature.

The engine brake horsepower was obtained from the engine manufacturer's chart, using the recorded values of engine speed, manifold pressure, back pressure, and carburetor-air temperature. The turbosupercharger nozzle-box entrance pressures are the averages of the five pressures indicated by the total-tube survey at the nozzle-box entrance. The

five pressures of the total-tube survey just aft of the exhaust collector ring were averaged to obtain the total pressure at this point, and the difference between this and the average pressure at the nozzle-box entrance is presented in table II as the pressure drop across the heat exchanger.

In table II, the heat-exchanger heated-air temperature is the average value of the five temperatures obtained with the five thermocouple survey located in the heated-air-discharge duct. The rate of heat transfer to the air was computed by the use of the following equation:

$$Q = W_h c_p (T_h - T_a - \Delta t_a)$$

where

$Q$ rate of heat transfer, Btu per hour

$W_h$ air-flow rate through the heat exchanger, pounds per hour

$c_p$ specific heat of air at the average of $T_h$ and $T_a$, Btu per pound, $^{\circ}F$

$T_h$ heated-air temperature, $^{\circ}F$

$T_a$ atmospheric temperature, $^{\circ}F$

$\Delta t_a$ adiabatic temperature rise, $^{\circ}F$

The results of the tests are presented in graphic form to show the effect of the heat exchanger on the factors affecting the operation of the engine and the turbosupercharger. Before a comparison could be made between the engine and the turbosupercharger operation with the standard exhaust stack installed and with the heat exchanger in place, it was necessary to cross-plot the data in order to correct for variations in engine speed. This was done by plotting the

data for the various engine speeds, fairing curves through these data, making a cross plot from the faired curves showing the variation of the particular factor with engine speed, and replotting from the cross plot at the same engine speed for both the standard-exhaust-stack and the heat-exchanger installations.

The heat-exchanger-performance characteristics of air-flow rate through the heat exchanger, air-temperature rise above atmospheric temperature, and rate of heat transfer are shown in figure 12. Figure 13 presents the exhaust-gas-flow rates and the exhaust-gas temperature and total-pressure drops across the heat exchanger and across the same length of standard exhaust stack. The data obtained for the factors shown on figures 12 and 13 did not show a clearly defined variation with engine speed; therefore, a single curve was faired through the points. The test points are not shown in the figures because the values of engine air-flow rate were corrected for variation in engine speed between the heat-exchanger tests and standard-stack tests before plotting. As noted in figure 13, the exhaust-gas-flow rate is the sum of the engine-air and fuel-flow rates obtained with the calibrated carburetor.

The effect of the heat-exchanger installation on engine back pressure is shown in figure 14. The form of this plot is not the same as that used for figures 12, 13, 15, and 16 because the scattering of the experimental points did not

make it possible to cross-plot the data. The effect of the heat-exchanger installation on the ideal work of expansion of the exhaust gas in flowing through the turbine of the turbo-supercharger may be determined from figure 15. The ideal work was computed from the test data by the method given in reference 5, which uses the following equation:

$$E = R_e T_{e_2} \frac{r}{r-1} \left[ 1 - \left( \frac{P_a}{H_{e_2}} \right)^{\frac{r-1}{r}} \right]$$

where

E ideal energy, foot-pounds per pound

$R_e$ gas constant for the exhaust gas, foot-pounds per pound, $^{\circ}F$

$T_{e_2}$ exhaust-gas temperature at nozzle-box entrance, $^{\circ}F$ absolute

r ratio of specific heats

$H_{e_2}$ total pressure at nozzle-box entrance, pounds per square foot

$P_a$ atmospheric air pressure, pounds per square foot

The effect of the heat-exchanger installation on the exhaust gas-flow rate through the turbine is shown in figure 16. The total exhaust-gas-flow rate is the sum of the engine air-flow rate and fuel-flow rate, and the turbine-flow rate is the difference between this total flow rate and the exhaust-gas-flow rate through the turbosupercharger waste gate.

The engine and turbosupercharger operating conditions of engine brake horsepower, turbosupercharger waste-gate-valve position, engine manifold pressure, engine speed, and turbosupercharger speed are shown in figure 17 for both the heat-exchanger and standard-exhaust-stack installations. The altitude variation of the engine back pressure, engine manifold pressure, turbosupercharger waste-gate-valve position, and turbosupercharger speed are given in figure 18 for the two test installations.

An estimate of the precision of the test data is as follows:

Pressure altitude, ±100 feet

Atmospheric temperature, ±2° F

Indicated airspeed, ±2 miles per hour

Engine speed, ±10 rpm

All pressures, ±0.1 inch of mercury

Air-flow rates, ±5 percent

Engine fuel-flow rate, ±10 percent

Exhaust-gas-flow rate through turbosupercharger waste gate, ±6 percent

Carburetor-air temperature, ±10° F

Temperature of air at heat-exchanger outlet, ±10° F

Exhaust-gas temperature, ±40° F

Turbosupercharger waste-gate-valve position, ±1°

Turbosupercharger speed, ±500 rpm

## DISCUSSION

### General

The results of these tests indicated that the effects of the heat-exchanger installation on engine back pressure and turbosupercharger operation did not limit the range of engine powers attainable for normal operation of the test airplane at the three test altitudes. The decrease in engine brake horsepower due to the increase in engine back pressure caused by the heat exchanger was found to be a maximum of about one-half percent. The limitations of engine power due to the heat exchanger causing a greater closure of the turbosupercharger waste-gate valve were found to occur only below an engine speed of 1800 rpm and were beyond the range of normal engine operation. Above this engine speed, complete closure of the waste-gate valve did not occur and the maximum permissible engine manifold pressures were obtained when the heat exchanger was installed. For other turbosupercharger-engine-airplane combinations in which the demands upon the supercharger require operation at more nearly maximum capacity to achieve the normal range of engine power than is the case for the test airplane, a heat exchanger may limit the power-plant operation.

The variation of the engine operating conditions with pressure altitude for rated and maximum cruise powers indicated that, for both installations, the maximum operating speed of the turbosupercharger would be reached before the waste-gate

valve would be fully closed and, therefore, the increase in waste gate closure caused by the heat exchanger was not enough to affect the critical altitude at these power conditions.

## Detail

The plate-type heat exchanger used for these tests exhibited performance characteristics which compare with the design requirements for the outboard heat-exchanger installation in the test airplane as follows:

| | Design requirements | Test data |
|---|---|---|
| Pressure altitude, ft . . . . . . | 18,000 | 17,000 |
| Indicated airspeed, mph . . . . . | 155 | 150 |
| Air-flow rate through exchanger, lb/hr. . . . . . . . . . . . . | 3500 | 3650 |
| Air-temperature rise, °F . . . | 295 to 325 | 265 |
| Rate of heat transferred to the air, Btu/hr . . . . . . . . . . . | 256,000 | 240,000 |
| Exhaust-gas total-pressure drop, in. of water. . . . . . . . . . | 7.3 | 9.5 |
| Exhaust-gas-flow rate, lb/hr . . | 3000 | 4400 |

This comparison with design requirements indicates that the performance of the test installation was in close enough agreement with design values to provide a good indication of the effect on engine and turbosupercharger operation of a heat exchanger suitable for the thermal ice-prevention equipment of the test airplane.

The exhaust-gas-flow rates presented in figure 13 are the sums of engine-air-flow rate and fuel-flow rate, or charge-flow rate, measured at the carburetor and, therefore, are not corrected for any leakage in the induction or exhaust system between the carburetor and the turbosupercharger. A limited amount of data obtained on the gas leakage with the straight stack in place indicated that it varied from 5 to 12 percent of the engine charge-flow rate; however, the information obtained was not complete enough to warrant correcting the data for the straight stack installation. No information was obtained on the gas leakage with the heat exchanger installed.

The variation of the exhaust-gas total-pressure drop across the heat exchanger and the equal length of standard exhaust stack shown in figure 13 agrees with theoretical calculations up to engine air-flow rates of about 4000 pounds per hour, but is less than calculated values at higher flow rates. Very few experimental points were obtained in the region of high flow rates and these showed considerable dispersion. It is probable, therefore, that a change in the flow conditions at the higher flow rates seriously affected the pressure measurements. Although the absolute values may be in error, it is believed that the data provide a fair indication of the increase in pressure drop caused by the heat exchanger.

The exhaust-gas temperature-drop curves show that the gas temperature at the turbosupercharger nozzle-box entrance was decreased 250 to 300° F by the heat-exchanger installation.

A comparison of the rate of heat transfer to the air, given in figure 13, with the rate of heat loss from the exhaust gas indicated that the heat lost from the exhaust gas was greater than the heat transferred to the air, or that there was an apparent net heat loss. The rate of heat loss from the exhaust gas was computed from the values of exhaust-gas flow rates and temperature drops presented in figure 14, with the latter decreased by 50°F to allow for a normal heat loss approximately equal to that with the standard exhaust stack installed. Difficulties encountered in instrumenting the exhaust system are believed to be responsible for the failure to obtain a satisfactory heat balance. The factors affecting the heat balance which could not be evaluated because of restrictions imposed on the instrumentation are (1) heat losses which may not be completely accounted for by allowing for a normal heat loss equal to that with the standard exhaust stack installed, (2) leakage in the induction system downstream of the carburetor and in the exhaust system and (3) the use of a single temperature measurement as the average temperature of the exhaust gas in the unlagged exhaust stack in front of and behind the heat exchanger. An analysis of the data indicated that the apparent net heat loss, expressed in percent, increased with an increase in exhaust gas flow rate. For example, for the tests at 24,000 feet altitude the apparent net heat loss increased from about 1.6 percent at an exhaust-gas flow rate of 1680 pounds per hour to about 49.5 percent at a flow rate of 5290 pounds per hour. A

similar variation was noted for the tests at 17,000 and 10,000 feet. It was also found that at the same exhaust-gas flow rates the apparent heat loss decreased with a decrease in altitude, except at the lowest flow rate where a slight indication of a reverse in this variation was found. This variation of the heat loss with gas flow rate tends to indicate that leakage was an important factor, and that possibly the errors introduced by the other factors affecting the heat balance varied with exhaust-gas flow rate.

The curves faired through the test data presented in figure 14 show an increase in back pressure caused by the heat exchanger of from about 0.1 inch of mercury at 10,000 feet pressure altitude to a maximum of about 1 inch of mercury at 24,000 feet pressure altitude. The maximum increase in engine back pressure caused by the heat exchanger was evaluated from the engine chart to represent a decrease in engine power of 6 brake horsepower at an engine speed of 2300 rpm and manifold pressure of 38 inches of mercury absolute, or about one-half percent of the total engine power at this operating condition. The engine-back-pressure data were not very consistent, as indicated by the scatter of points plotted in figure 14. This scattering is believed to be due to pulsations in the exhaust-gas flow which were not accurately recorded and to the poor location available for the pressure orifice in the exhaust system.

The decrease of ideal work of expansion per pound of

exhaust gas caused by the heat-exchanger installation, is shown in figure 15 to be as high as about 50 percent, at low engine speeds, and never less than 10 percent of the ideal work for the standard stack installation. In order to provide the same total energy for supercharging, it is apparent that, because of this decrease in ideal work per pound of exhaust gas per minute, a greater quantity of gas must flow through the turbine when the heat exchanger is installed. An indication of this increase in the quantity of exhaust gas flowing through the turbine may be obtained from figure 16. The lines of constant turbosupercharger waste-gate-valve position shown in figure 16 were included to illustrate how the turbosupercharger control was affected. The curves indicate that, at low engine speeds the relationship between the exhaust-gas-flow rate through the turbine and air-flow rate to the engine is such that closed waste-gate-valve position is required, but as the engine speed is increased this condition becomes less critical.

The over-all effect of the heat-exchanger installation on the engine and turbosupercharger operation is presented as figure 17. The increased closure of the turbosupercharger waste-gate valve to obtain the same engine brake horsepower with the heat exchanger installed is shown to be more critical at the low engine speeds than at the high engine speeds. One of the most important engine operating conditions in the low-power range is that for maximum range cruising which, in accordance with the operating instructions given in reference

6, was found to be the following for the test airplane:

| Pressure altitude, (ft) | Engine speed, (rpm) | Engine manifold pressure (in. Hg abs.) |
|---|---|---|
| 10,000 | 1550 | 29 |
| 17,000 | 1800 | 29 |
| 24,000 | 2050 | 29 |

Figure 17 shows that these operating conditions were obtainable with the heat exchanger installed. In general, figure 17 indicates that, for engine speeds of 1800 rpm and above, the increased closure of the turbosupercharger waste-gate valve caused by the heat exchanger was not sufficient to prevent obtaining the same maximum engine manifold pressure and power that was obtained with the standard exhaust stack in place. Below an engine speed of 1800 rpm when the heat exchanger was installed, closed waste-gate-valve position was frequently reached before the maximum operating powers for the standard stack installation were attained. It is believed, however, that the engine-power conditions (fig. 17) limited by the heat-exchanger installation are below the range of normal operation and, therefore, are not critical.

The differences in turbosupercharger speed between the standard-exhaust-stack and heat-exchanger installations at the same engine powers (figs. 17 and 18) are not believed to be correct. When the operating conditions at the same engine

power for both the heat-exchanger and standard exhaust-stack installations were used, the supercharger speeds determined from the compressor chart for the type B-2 turbosupercharger were essentially the same with a maximum variation of 500 rpm. The speeds ascertained from the compressor chart were within 500 rpm of the test data for the heat-exchanger installation, and it is probable, therefore, that these values are more nearly correct than those for the standard-stack installation. The discrepancy in the test data may be due to an error incurred in the installation of the recording tachometer.

In figure 18, it is shown that rated power (1000 bhp), maximum cruise power (750 bhp), and an average normal cruise power (600 bhp) could be maintained for the range of test altitudes with the heat exchanger installed. At these powers the turbosupercharger waste-gate valve was further closed when the heat exchanger was installed than when the standard stack was in place, but the data indicate that, for both the 1000- and 750-brake horsepower conditions, the maximum operating speed of the turbosupercharger would be reached before the waste-gate valve would be fully closed.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif., August 23, 1945.

## REFERENCES


1. Jones, Alun R., and Rodert, Lewis A.: Development of Thermal Ice-Prevention Equipment for the B-24D Airplane. NACA ACR, Feb. 1943. (Classification changed to "Restricted" Aug. 1943.)

2. Jones, Alun R., and Rodert, Lewis A.: Development of Thermal Ice-Prevention Equipment for the B-17F Airplane. NACA ARR No. 3H24, 1943.

3. Look, Bonne C., and Selna, James: Flight Tests of Several Exhaust-Gas-to-Air Heat Exchangers in a B-17F Airplane. NACA RMR, Apr. 1944.

4. Anon.: Erection and Maintenance Instructions for Army Model B-17F. T.O. No. 01-20EF-2, U.S. Army Air Forces, Dec. 1, 1942 (revised Apr. 5, 1945).

5. Pinkel, Benjamin, and Turner, L. Richard: Thermodynamic Data for the Computation of the Performance of Exhaust-Gas Turbines. NACA ARR No. 4B25, 1944.

6. Anon.: Pilot's Flight Operating Instructions for Army Model B-17F. T.O. No. AN01-20EF-1, U.S. Army Air Forces, June 20, 1944 (revised Apr. 25, 1945).

TABLE I.– TEST RESULTS OBTAINED WITH STANDARD EXHAUST STACK INSTALLED IN NACELLE 4 OF THE TEST AIRPLANE



| Run No. | Flight conditions: Pressure alt. (ft) | Flight conditions: Ambient air temp., $T_a$ (°F) | Flight conditions: I.A.S. (mph) | Engine conditions: Fuel air mixture | Speed (rpm) | M.P., $P_m$ (in. Hg abs.) | Exhaust back pressure, $P_{e_1}$ (in. Hg abs.) | Carburetor air temp., $T_o$ (°F) | Carburetor total pressure $H_3$ (in. Hg abs.) | Air flow rate $W_c$ (lb/hr) | Fuel flow rate (lb/hr) | Fuel air ratio | bhp | Turbo speed (rpm) | Turbo waste gate position, open (fully open at 76°) (deg) | Turbo waste gate exhaust flow, $W_{e_3}$ (lb/hr) | Exhaust temp. at collector ring outlet, $T_{e_1}$ (°F) | Exhaust temp. at turbo nozzle box entrance $T_{e_2}$ (°F) | Total pressure at nozzle box, $H_{e_2}$ (in. Hg abs.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10,000 feet altitude flight | | | | | | | | | | | | | | | | | | | |
| 1 | 10000 | 39 | 150 | AR | 2330 | 38.1 | 28.6 | 69 | 26.6 | 6460 | 541 | 0.0837 | 970 | 12100 | 32.0 | 3220 | 1586 | 1568 | 29.5 |
| 2 | 9950 | -- | 149 | AR | 2330 | 33.8 | 26.3 | 64 | 23.4 | 5690 | 469 | .0824 | 855 | 9700 | 37.5 | 3190 | 1581 | 1534 | 26.8 |
| 3 | 9900 | 41 | 149 | AR | 2330 | 30.8 | 24.7 | 58 | 21.0 | 5130 | 413 | .0805 | 770 | 7200 | 44.0 | 3300 | 1600 | 1556 | 24.8 |
| 4 | 10000 | 40 | 148 | AR | 2330 | 27.1 | 22.6 | 61 | 18.6 | 4490 | 349 | .0777 | 665 | 3900 | 74.5 | 3670 | 1626 | 1586 | 22.9 |
| 5 | 10000 | 40 | 150 | AL | 2015 | 26.6 | 22.2 | 61 | 19.7 | 3830 | 252 | .0658 | 610 | 3500 | 75.0 | 3060 | 1715 | 1648 | 22.3 |
| 6 | 10000 | 40 | 150 | AL | 2015 | 28.2 | 22.7 | -- | 20.9 | ---- | --- | ------ | 665 | 5600 | 46.5 | 2690 | 1706 | 1648 | 23.3 |
| 7 | 9900 | 40 | 149 | AR | 2015 | 30.2 | 23.9 | 59 | 22.6 | 4520 | 351 | .0776 | 715 | 7400 | 38.5 | 2520 | 1609 | 1572 | 24.3 |
| 8 | 9900 | 40 | 149 | AR | 2015 | 33.5 | 25.7 | 64 | 25.0 | 5000 | 400 | .0800 | 800 | 9700 | 31.0 | 2410 | 1560 | 1530 | 26.1 |
| 9 | 9850 | 40 | 146 | AR | 1820 | 31.5 | 24.7 | 60 | 24.5 | 4270 | 325 | .0761 | 705 | 8700 | 30.0 | 1970 | 1622 | 1564 | 24.9 |
| 10 | 9950 | 40 | 150 | AL | 1830 | 29.8 | 23.6 | 59 | 22.8 | 4060 | 271 | .0668 | 665 | 7400 | 34.5 | 2070 | 1648 | 1635 | 24.0 |
| 11 | 10000 | 40 | 149 | AL | 1820 | 28.0 | 22.7 | -- | 21.5 | ---- | --- | ------ | 615 | 5800 | 42.5 | 2300 | 1670 | 1635 | 23.1 |
| 12 | 10150 | 39 | 147 | AL | 1820 | 26.0 | 22.0 | 58 | 20.0 | 3470 | 225 | .0648 | 555 | 3300 | 76.0 | 2960 | 1670 | 1622 | 21.8 |
| 13 | 10000 | 40 | 148 | AL | 1700 | 25.6 | 21.7 | 58 | 20.3 | 3140 | 202 | .0643 | 520 | 3000 | 76.0 | 2570 | 1622 | 1551 | 21.7 |
| 14 | 10000 | 41 | 147 | AL | 1700 | 27.7 | 22.8 | 53 | 21.9 | 3420 | 222 | .0649 | 575 | 5700 | 37.0 | 2320 | 1648 | 1643 | 22.9 |
| 15 | 10050 | 40 | 147 | AL | 1700 | 29.5 | 23.8 | 54 | 23.3 | 3580 | 234 | .0654 | 620 | 7600 | 28.5 | 1610 | 1660 | 1635 | 23.7 |
| 16 | 10100 | 40 | 147 | AR | 1700 | 32.6 | 25.4 | 61 | 25.9 | 4020 | 300 | .0746 | 695 | 10100 | 20.5 | 1310 | 1630 | 1600 | 25.4 |
| 17 | 10100 | 40 | 148 | AR | 1610 | 31.7 | 24.5 | 64 | 25.7 | 3700 | 266 | .0719 | 635 | 9600 | 18.3 | 1290 | 1622 | 1560 | 24.8 |
| 18 | 10050 | 40 | 147 | AL | 1610 | 29.7 | 23.5 | 56 | 23.8 | 3450 | 223 | .0646 | 590 | 7700 | 25.5 | 1420 | 1630 | 1591 | 23.8 |
| 19 | 10050 | 39 | 147 | AL | 1610 | 27.3 | 22.5 | 53 | 22.2 | 3250 | 209 | .0643 | 540 | 5800 | 33.5 | 1680 | 1600 | 1560 | 22.7 |
| 20 | 9950 | 41 | 147 | AL | 1610 | 25.3 | 21.6 | 57 | 20.4 | 3020 | 193 | .0639 | 490 | 2700 | 76.0 | 2170 | 1572 | 1512 | 21.6 |
| 21 | 10000 | 40 | 147 | AL | 1520 | 25.0 | 21.5 | 59 | 20.6 | 2750 | 173 | .0629 | 450 | 2400 | 76.0 | 2200 | 1534 | 1480 | 21.4 |
| 22 | 10000 | 40 | 148 | AL | 1530 | 27.2 | 22.6 | 53 | 22.3 | 3100 | 199 | .0642 | 505 | 5700 | 30.0 | 1430 | 1555 | 1520 | 22.6 |
| 23 | 10000 | 40 | 147 | AL | 1520 | 29.3 | 23.6 | 59 | 24.3 | 3350 | 216 | .0645 | 550 | 7800 | 18.8 | 1050 | 1572 | 1534 | 23.8 |
| 24 | 10000 | 38 | 149 | AR | 1530 | 30.8 | 24.6 | 60 | 25.4 | 3510 | 245 | .0698 | 585 | 9300 | 14.0 | 960 | 1564 | 1512 | 24.5 |
| 25 | 9900 | 38 | 150 | AL | 1440 | 29.5 | 24.2 | 55 | 24.9 | 3080 | 198 | .0643 | 510 | 8500 | 9.0 | 730 | 1503 | 1441 | 24.0 |
| 26 | 9900 | 39 | 150 | AL | 1440 | 27.9 | 23.0 | -- | 23.5 | ---- | --- | ------ | 480 | 7100 | 17.5 | 880 | 1498 | 1432 | 23.1 |
| 27 | 10000 | 39 | 147 | AL | 1440 | 26.3 | 23.0 | 50 | 22.1 | 2750 | 172 | .0625 | 455 | 5200 | 29.0 | 1265 | 1498 | 1454 | 22.2 |
| 28 | 9950 | 39 | 147 | AL | 1430 | 24.5 | 21.4 | 53 | 20.6 | 2540 | 155 | .0610 | 410 | 2300 | 75.0 | 2040 | 1498 | 1450 | 21.3 |
| 17,000 feet altitude flight | | | | | | | | | | | | | | | | | | | |
| 1 | 16800 | 15 | 149 | AR | 2340 | 38.0 | 27.6 | 41 | 25.5 | 6640 | 564 | 0.0850 | 1000 | 15700 | 29.5 | 3100 | 1617 | 1564 | 28.0 |
| 2 | 17050 | -- | 148 | AR | 2340 | 31.9 | 23.0 | 32 | 21.2 | 5600 | 462 | .0825 | 805 | 12800 | 33.0 | 2780 | 1577 | 1512 | 23.6 |
| 3 | 17000 | 14 | 147 | AR | 2330 | 26.8 | 19.8 | 31 | 17.7 | 4740 | 373 | .0787 | 685 | 9700 | 39.0 | 2800 | 1577 | 1489 | 20.6 |
| 4 | 16800 | 14 | 149 | AR | 2340 | 21.3 | 17.1 | 31 | 13.8 | 3710 | 261 | .0703 | 515 | 4000 | 76.0 | 2950 | 1568 | 1534 | 17.6 |
| 5 | 16800 | 15 | 147 | AL | 2020 | 21.0 | 16.7 | 26 | 14.9 | 3130 | 197 | .0630 | 485 | 3400 | 76.0 | 2480 | 1630 | 1547 | 17.0 |
| 6 | 16750 | 15 | 147 | AL | 2020 | 24.7 | 18.7 | 38 | 17.5 | 3670 | 226 | .0616 | 590 | 7800 | 37.5 | 1970 | 1679 | 1635 | 19.1 |
| 7 | 16800 | 14 | 149 | AR | 2020 | 29.3 | 21.7 | 58 | 21.2 | 4380 | 335 | .0765 | 700 | 10700 | 29.0 | 1890 | 1572 | 1538 | 21.8 |
| 8 | 16900 | 15 | 148 | AR | 2020 | 36.3 | 25.6 | 47 | 26.1 | 5480 | 450 | .0821 | 895 | 15500 | 24.0 | 2050 | 1581 | 1516 | 26.2 |
| 9 | 16800 | 15 | 149 | AR | 1830 | 31.3 | 22.5 | 39 | 24.0 | 4230 | 317 | .0749 | 725 | 13300 | 20.8 | 1420 | 1617 | 1586 | 23.0 |
| 10 | 16750 | 15 | 148 | AL | 1820 | 27.5 | 20.2 | 31 | 20.9 | 3860 | 238 | .0617 | 625 | 10700 | 25.5 | 2110 | 1679 | 1635 | 20.6 |
| 11 | 16800 | 16 | 147 | AL | 1820 | 24.0 | 18.7 | 31 | 18.2 | 3350 | 210 | .0627 | 535 | 8000 | 32.0 | 1590 | 1640 | 1595 | 18.9 |
| 12 | 16800 | 14 | 148 | AL | 1820 | 20.5 | 16.7 | 33 | 15.4 | 2780 | 175 | .0630 | 440 | 3300 | 75.0 | 2250 | 1581 | 1516 | 16.8 |
| 13 | 16800 | 15 | 148 | AR | 1720 | 30.5 | 22.1 | 25 | 23.9 | 4130 | 307 | .0743 | 685 | 13000 | 16.0 | 820 | 1621 | 1586 | 22.4 |
| 14 | 16800 | 15 | 147 | AL | 1720 | 27.0 | 20.2 | 42 | 21.2 | 3500 | 217 | .0620 | 585 | 10700 | 21.5 | 1170 | 1630 | 1577 | 20.5 |
| 15 | 16800 | 15 | 145 | AL | 1720 | 24.1 | 18.7 | 31 | 18.6 | 3190 | 200 | .0627 | 515 | 8100 | 28.3 | 1340 | 1608 | 1568 | 18.9 |
| 16 | 16800 | 15 | 147 | AL | 1710 | 20.1 | 16.7 | 31 | 14.9 | 2600 | 165 | .0635 | 410 | 3000 | 75.0 | 2120 | 1534 | 1467 | 16.7 |
| 17 | 16850 | 15 | 151 | AR | 1610 | 31.2 | 22.7 | 48 | 25.0 | 3820 | 274 | .0717 | 655 | 13700 | 7.5 | 600 | 1608 | 1547 | 23.0 |
| 18 | 16750 | 16 | 148 | AL | 1610 | 27.8 | 20.9 | 42 | 22.2 | 3430 | 216 | .0630 | 575 | 11800 | 12.0 | 720 | 1608 | 1525 | 21.0 |
| 19 | 16700 | 16 | 148 | AL | 1610 | 23.8 | 18.8 | 31 | 18.8 | 2920 | 184 | .0630 | 475 | 8100 | 23.5 | 1050 | 1556 | 1520 | 18.8 |
| 20 | 16800 | 15 | 148 | AL | 1610 | 19.8 | 16.7 | 30 | 15.7 | 2440 | 155 | .0635 | 380 | 2600 | 75.0 | 1980 | 1480 | 1415 | 16.6 |
| 21 | 16800 | 15 | 147 | AL | 1540 | 19.5 | 16.5 | 31 | 15.7 | 2220 | 142 | .0640 | 360 | 2200 | 75.0 | 1870 | 1415 | 1363 | 16.5 |
| 22 | 16800 | 14 | 148 | AL | 1530 | 23.5 | 18.6 | 31 | 19.3 | 2800 | 177 | .0632 | 450 | 8400 | 18.5 | 850 | 1516 | 1445 | 18.7 |
| 23 | 16750 | 15 | 148 | AL | 1540 | 26.6 | 19.9 | 36 | 21.7 | 3220 | 202 | .0628 | 515 | 11100 | 9.7 | 620 | 1560 | 1520 | 20.3 |
| 24 | 16700 | 15 | 147 | AL | 1530 | 29.9 | 21.9 | 49 | 24.6 | 3510 | 217 | .0618 | 585 | 13400 | 3.5 | 420 | 1600 | 1525 | 22.3 |
| 25 | 16750 | 15 | 147 | AL | 1480 | 26.8 | 20.6 | 38 | 22.3 | 2980 | 187 | .0628 | 495 | 11700 | .2 | .0 | 1525 | 1471 | 20.5 |
| 26 | 16800 | 15 | 147 | AL | 1470 | 24.7 | 19.4 | -- | 20.6 | ---- | --- | ------ | 445 | 10000 | 5.8 | 250 | 1480 | 1467 | 19.3 |
| 27 | 16900 | 14 | 146 | AL | 1470 | 22.0 | 17.7 | 24 | 18.4 | 2450 | 156 | .0637 | 400 | 7300 | 18.3 | 710 | 1459 | 1394 | 17.9 |
| 28 | 16950 | 14 | 150 | AL | 1470 | 19.1 | 16.2 | 29 | 15.8 | 2090 | 134 | .0641 | 345 | 2100 | 75.0 | 1710 | 1377 | 1320 | 16.3 |
| 24,000 feet altitude flight | | | | | | | | | | | | | | | | | | | |
| 1 | 24000 | -14 | 147 | AR | 2320 | 38.0 | 27.4 | 68 | 25.0 | 6460 | 575 | 0.0890 | 970 | 19100 | 28.3 | 3230 | 1614 | 1614 | 27.4 |
| 2 | 23800 | -- | 147 | AR | 2330 | 31.5 | 21.7 | 40 | 20.6 | 5580 | 479 | .0858 | 825 | 16300 | 30.5 | 2770 | ---- | ---- | 22.8 |
| 3 | 23700 | -14 | 141 | AR | 2320 | 16.3 | 13.2 | 13 | 10.3 | 2790 | 209 | .0749 | 380 | 3800 | 73.5 | 2340 | 1510 | 1465 | 13.2 |
| 4 | 23900 | -14 | 147 | AR | 2320 | 24.1 | 17.0 | 14 | 15.7 | 4290 | 351 | .0818 | 600 | 12200 | 34.3 | 2290 | 1680 | 1619 | 17.7 |
| 5 | 23800 | -13 | 144 | AL | 2020 | 15.8 | 12.7 | 7 | 11.1 | 2490 | 175 | .0702 | 350 | 3300 | 74.0 | 1990 | 1542 | 1504 | 12.8 |
| 6 | 23850 | -14 | 146 | AL | 2020 | 21.3 | 15.5 | 9 | 15.0 | 3320 | 221 | .0666 | 515 | 10000 | 31.8 | 1720 | 1660 | 1598 | 15.6 |
| 7 | 23900 | -13 | 147 | AR | 2030 | 26.4 | 17.9 | 21 | 18.6 | 4140 | 336 | .0812 | 655 | 13800 | 26.2 | 1700 | 1708 | 1663 | 18.7 |
| 8 | 24000 | -14 | 148 | AR | 2030 | 32.4 | 22.1 | 38 | 22.8 | 4940 | 414 | .0838 | 830 | 16900 | 23.7 | 1880 | 1610 | 1575 | 22.9 |
| 9 | 23750 | -13 | 147 | AR | 1820 | 31.2 | 21.7 | 38 | 23.1 | 4280 | 350 | .0818 | 730 | 16900 | 17.3 | 1660 | 1680 | 1637 | 21.9 |
| 10 | 23800 | -14 | 147 | AL | 1820 | 26.8 | 18.7 | 22 | 20.0 | 3800 | 248 | .0653 | 625 | 14800 | 20.3 | 1130 | 1720 | 1662 | 18.8 |
| 11 | 23800 | -13 | 148 | AL | 1820 | 21.6 | 15.7 | 10 | 16.0 | 3080 | 208 | .0676 | 515 | 11000 | 25.8 | 1190 | 1635 | 1577 | 15.8 |
| 12 | 23750 | -14 | 145 | AL | 1820 | 15.4 | 12.7 | 3 | 11.3 | 2190 | 156 | .0712 | 320 | 3000 | 74.0 | 1620 | 1483 | 1444 | 12.6 |
| 13 | 23800 | -14 | 145 | AL | 1710 | 15.2 | 12.7 | -2 | 11.4 | 1920 | 140 | .0729 | 310 | 2800 | 74.0 | 1740 | 1457 | 1376 | 12.5 |
| 14 | 23800 | -14 | 147 | AL | 1710 | 20.0 | 15.0 | 1 | 15.1 | 2770 | 191 | .0690 | 435 | 9700 | 25.0 | 960 | 1589 | 1537 | 15.0 |
| 15 | 23800 | -14 | 150 | AL | 1720 | 25.2 | 17.7 | 16 | 19.6 | 3480 | 230 | .0661 | 565 | 14100 | 17.0 | 900 | 1651 | 1624 | 18.2 |
| 16 | 23900 | -14 | 148 | AR | 1710 | 30.2 | 21.6 | 32 | 22.9 | 3970 | 320 | .0806 | 670 | 16800 | 12.8 | 990 | 1668 | 1615 | 21.4 |
| 17 | 23850 | -14 | 147 | AR | 1610 | 31.2 | 21.7 | 36 | 24.3 | 3800 | 305 | .0803 | 660 | 17700 | 6.7 | 530 | 1646 | 1593 | 21.8 |
| 18 | 23800 | -14 | 145 | AR | 1620 | 26.0 | 18.0 | 23 | 20.6 | 3270 | 253 | .0774 | 550 | 15000 | 8.0 | 570 | 1597 | 1570 | 18.6 |
| 19 | 23900 | -15 | 146 | AL | 1620 | 21.0 | 15.4 | 7 | 16.4 | 2630 | 182 | .0692 | 450 | 11200 | 15.7 | 680 | 1631 | 1517 | 15.6 |
| 20 | 23850 | -14 | 145 | AL | 1620 | 15.0 | 12.1 | 2 | 11.7 | 1880 | 137 | .0729 | 295 | 2700 | 74.5 | 1590 | 1403 | 1321 | 12.3 |
| 21 | 23950 | -14 | 148 | AL | 1560 | 30.2 | 21.5 | 31 | 23.9 | 3800 | 248 | .0653 | 610 | 17600 | 2.5 | 210 | 1635 | 1587 | 21.4 |
| 22 | 23950 | -14 | 147 | AL | 1530 | 25.8 | 18.5 | 23 | 20.8 | 3090 | 208 | .0673 | 510 | 15300 | 2.7 | 260 | 1595 | 1612 | 18.6 |
| 23 | 23850 | -14 | 149 | AL | 1540 | 20.6 | 15.2 | 9 | 16.4 | 2400 | 170 | .0708 | 410 | 11000 | 10.7 | 460 | 1528 | 1546 | 15.3 |
| 24 | 23800 | -- | 145 | AL | 1530 | 14.8 | 12.1 | -- | 11.7 | 1750 | 130 | .0743 | 270 | 2200 | 74.0 | 1550 | ---- | ---- | 12.3 |
| 25 | 23800 | -14 | 146 | AL | 1450 | 14.6 | 11.7 | 3 | 11.8 | 1655 | 124 | .0749 | 255 | 1900 | 74.0 | 1390 | 1272 | 1216 | 12.1 |
| 26 | 23850 | -- | 144 | AL | 1440 | 17.0 | 13.5 | -- | 13.7 | 1945 | 142 | .0730 | 305 | 7100 | 19.0 | 640 | ---- | ---- | 13.5 |
| 27 | 23900 | -14 | 147 | AL | 1440 | 21.7 | 15.6 | -- | 17.3 | 2400 | 170 | .0708 | 400 | 12500 | 0 | 0 | 1478 | 1443 | 15.9 |
| 28 | 23950 | -14 | 146 | AL | 1440 | 19.0 | 14.5 | 5 | 15.1 | 2270 | 162 | .0714 | 345 | 10000 | 6.3 | 220 | 1443 | 1383 | 14.6 |
| 29 | 23900 | -13 | 145 | AL | 1540 | 14.8 | 12.0 | -2 | 11.9 | 1810 | 133 | .0735 | 280 | 2400 | 76.0 | 1330 | 1379 | 1297 | 12.2 |

TABLE II.– TEST RESULTS OBTAINED WITH PLATE TYPE HEAT EXCHANGER INSTALLED IN NACELLE 4 OF THE TEST AIRPLANE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

| Flight conditions | | | | Engine conditions | | | | | | | | | | | | | | | | Heat exchanger conditions | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run No. | Pressure alt. (ft) | Atmosphere temp., $T_a$ (°F) | I.A.S. (mph) | Fuel air mixture | Speed (rpm) | M.P., $P_m$ (in. Hg abs.) | Exhaust back pressure, $P_{e_1}$ (in. Hg abs.) | Carburetor air temp., $T_c$ (°F) | Carburetor total pressure, $H_c$ (in. Hg abs.) | Air flow rate, $W_c$ (lb/hr) | Fuel flow rate (lb/hr) | Fuel air ratio | bhp | Turbo speed (rpm) | Turbo waste gate position, open (fully open at 76°) (deg) | Turbo waste gate exhaust flow, $W_{e_3}$ (lb/hr) | Exhaust temp. at collector ring outlet, $T_{e_1}$ (°F) | Exhaust temp. at turbo nozzle box entrance, $T_{e_2}$ (°F) | Total pressure at nozzle box, $H_{e_2}$ (in. Hg abs.) | Total pressure drop gas side, $H_{e_1}-H_{e_2}$ (in. Hg) | Air side flow rate, $W_h$ (lb/hr) | Heated air temp., $T_h$ (°F) | Rate of heat transfer (1000 Btu/hr) |
| 10,000 feet altitude flight | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 10000 | -- | 149 | AR | 2350 | 37.8 | 28.5 | 62 | 24.9 | 6470 | 540 | 0.0835 | 970 | 10800 | 28.8 | 2660 | ---- | ---- | 28.5 | 1.3 | ---- | --- | --- |
| 2 | 10000 | -- | 144 | AR | 2350 | 32.2 | 25.4 | 62 | 21.0 | 5440 | 465 | .0854 | 810 | 7250 | 36.4 | 2790 | ---- | ---- | 25.3 | 1.1 | ---- | --- | --- |
| 3 | 10000 | 41 | 146 | AR | 2350 | 29.1 | 23.7 | 61 | 18.9 | 4910 | 410 | .0835 | 720 | 4800 | 47.2 | 3110 | 1684 | 1335 | 23.7 | .6 | 4150 | 305 | 261 |
| 4 | 10000 | 42 | 153 | AR | 2350 | 27.1 | 22.6 | 60 | 17.6 | 4620 | 370 | .0801 | 660 | 2900 | 76.0 | 3490 | 1685 | 1313 | 22.6 | .8 | 4280 | 294 | 256 |
| 5 | 10000 | 44 | 148 | AR | 2010 | 32.4 | 25.2 | 59 | 23.5 | 4790 | 395 | .0824 | 770 | 8200 | 27.0 | 1890 | 1651 | 1360 | 25.2 | .7 | 4130 | 310 | 262 |
| 6 | 10000 | 42 | 149 | AR | 2010 | 29.0 | 23.4 | 56 | 20.8 | 4250 | 310 | .0730 | 675 | 5300 | 39.0 | 2310 | 1691 | 1391 | 23.6 | .4 | 4150 | 300 | 255 |
| 7 | 10000 | 42 | 149 | AL | 2010 | 27.2 | 22.6 | 61 | 19.5 | 3970 | 256 | .0645 | 625 | 3200 | 51.0 | 2710 | 1810 | 1493 | 22.7 | .3 | 4130 | 311 | 265 |
| 8 | 10000 | 42 | 147 | AL | 2010 | 26.6 | 22.5 | 60 | 18.9 | 3800 | 240 | .0632 | 585 | 2600 | 76.0 | 2950 | 1786 | 1461 | 22.1 | .5 | 4130 | 304 | 258 |
| 9 | 11000 | 42 | 149 | AR | 1820 | 31.0 | 24.2 | 56 | 23.5 | 4180 | 302 | .0722 | 690 | 7500 | 24.5 | 1510 | 1707 | 1378 | 24.5 | .8 | 4130 | 300 | 253 |
| 10 | 10000 | 43 | 151 | AL | 1820 | 29.3 | 23.4 | 54 | 22.2 | 3930 | 252 | .0641 | 650 | 6000 | 31.3 | 1755 | 1780 | 1459 | 23.7 | .7 | 4030 | 308 | 254 |
| 11 | 9950 | 42 | 141 | AL | 1820 | 27.8 | 22.6 | 58 | 20.9 | 3720 | 233 | .0626 | 610 | 4400 | 41.0 | 2160 | 1756 | 1420 | 22.6 | .7 | 4000 | 300 | 245 |
| 12 | 10000 | 42 | 144 | AL | 1830 | 26.1 | 21.8 | 61 | 19.7 | 3450 | 212 | .0615 | 565 | 2300 | 76.0 | 2740 | 1741 | 1415 | 21.8 | .5 | 4070 | 295 | 245 |
| 13 | 10000 | 42 | 147 | AL | 1720 | 25.8 | 21.6 | 63 | 20.0 | 3190 | 191 | .0599 | 530 | 2100 | 76.0 | 2580 | 1682 | 1404 | 21.6 | .4 | 4060 | 277 | 227 |
| 14 | 10000 | 41 | 145 | AR | 1730 | 32.9 | 25.4 | 60 | 25.6 | 4190 | 302 | .0721 | 715 | 9200 | 12.8 | 900 | 1728 | 1414 | 25.4 | .7 | 4060 | 296 | 246 |
| 15 | 9950 | 42 | 146 | AL | 1730 | 29.6 | 23.6 | 58 | 22.7 | 3740 | 235 | .0628 | 630 | 6500 | 25.4 | 1405 | 1750 | 1431 | 23.3 | .9 | 4230 | 292 | 281 |
| 16 | 10000 | 43 | 150 | AL | 1730 | 27.0 | 22.4 | 55 | 20.9 | 3360 | 205 | .0610 | 565 | 3900 | 40.0 | 1930 | 1728 | 1410 | 22.2 | .6 | 4170 | 291 | 246 |
| 17 | 10000 | 43 | 154 | AR | 1630 | 31.6 | 24.8 | 61 | 25.1 | 3900 | 253 | .0649 | 650 | 8750 | 9.3 | 710 | 1672 | 1362 | 24.7 | .8 | 4250 | 294 | 284 |
| 18 | 9900 | 42 | 152 | AL | 1640 | 29.6 | 23.9 | 60 | 23.5 | 3540 | 218 | .0616 | 605 | 6900 | 19.0 | 1000 | 1706 | 1377 | 23.7 | .5 | 4230 | 285 | 244 |
| 19 | 9950 | 44 | 147 | AL | 1630 | 27.3 | 22.6 | 56 | 21.6 | 3260 | 197 | .0605 | 545 | 4600 | 31.3 | 1485 | 1692 | 1363 | 22.5 | .5 | 4130 | 281 | 232 |
| 20 | 10000 | 42 | 145 | AL | 1620 | 25.4 | 21.8 | 63 | 20.1 | 2970 | 172 | .0579 | 495 | 1800 | 76.0 | 2420 | 1647 | 1311 | 21.5 | .2 | 4120 | 271 | 224 |
| 21 | 10000 | 42 | 145 | AL | 1540 | 24.9 | 21.7 | 62 | 20.3 | 2710 | 152 | .0561 | 450 | 1500 | 76.0 | 2150 | 1622 | 1120 | 21.3 | .3 | 4160 | 260 | 220 |
| 22 | 10000 | 43 | 150 | AR | 1530 | 30.2 | 24.3 | 62 | 24.6 | 3390 | 190 | .0561 | 575 | 8000 | 4.0 | 400 | 1605 | 1296 | 24.4 | .2 | 4230 | 266 | 224 |
| 23 | 10000 | 44 | 148 | AL | 1530 | 28.7 | 23.5 | 59 | 23.5 | 3240 | 195 | .0602 | 535 | 6750 | 13.7 | 725 | 1671 | 1279 | 23.3 | .5 | 4140 | 275 | 226 |
| 24 | 10000 | 44 | 150 | AL | 1530 | 26.5 | 22.5 | 58 | 21.6 | 2950 | 170 | .0576 | 485 | 4000 | 31.4 | 1300 | 1616 | 1232 | 22.0 | .4 | 4260 | 260 | 218 |
| 25 | 9950 | 43 | 145 | AL | 1450 | 29.1 | 23.8 | 61 | 24.3 | 3120 | 185 | .0593 | 520 | 7250 | .5 | 290 | 1617 | 1268 | 23.5 | .7 | 4160 | 260 | 214 |
| 26 | 10000 | 42 | 147 | AL | 1450 | 28.7 | 23.1 | 60 | 23.3 | 2830 | 160 | .0565 | 495 | 6300 | 9.4 | 510 | 1605 | 1262 | 22.9 | .4 | 4160 | 258 | 213 |
| 27 | 10000 | 44 | 148 | AL | 1450 | 26.6 | 22.4 | 61 | 22.2 | 2720 | 152 | .0559 | 460 | 4700 | 23.2 | 880 | 1623 | 1267 | 22.1 | .4 | 4230 | 248 | 208 |
| 28 | 10000 | 42 | 144 | AL | 1450 | 24.5 | 21.5 | 63 | 20.5 | 2490 | 140 | .0562 | 420 | 1200 | 76.0 | 2060 | 1574 | 1220 | 21.4 | .1 | 4130 | 244 | 197 |
| 17,000 feet altitude flight | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | ----- | 10 | 149 | AR | 2350 | 38.0 | 27.6 | 56 | 24.7 | 6530 | 550 | 0.0835 | 990 | 14900 | 24.6 | 2360 | 1648 | 1368 | 27.6 | 0.9 | 3660 | 325 | 273 |
| 2 | ----- | 9 | 146 | AR | 2350 | 21.0 | 17.4 | 36 | 13.3 | 3660 | 213 | .0582 | 500 | 2900 | 76.0 | 2300 | 1648 | 1338 | 17.2 | .7 | 3690 | 269 | 226 |
| 3 | ----- | 9 | 151 | AR | 2350 | 30.5 | 22.8 | 39 | 19.3 | 5400 | 445 | .0824 | 785 | 11300 | 29.0 | 2260 | 1621 | 1301 | 22.7 | .7 | 3760 | 296 | 255 |
| 4 | ----- | 9 | 150 | AR | 2350 | 27.6 | 21.1 | 35 | 17.6 | 4860 | 390 | .0802 | 695 | 9100 | 32.5 | 2250 | 1621 | 1296 | 20.6 | .9 | 3720 | 290 | 247 |
| 5 | ----- | 9 | 151 | AR | 2020 | 32.1 | 23.6 | 44 | 23.2 | 5000 | 405 | .0810 | 810 | 12700 | 20.0 | 1390 | 1646 | 1346 | 23.4 | .7 | 3720 | 291 | 248 |
| 6 | ----- | 9 | 150 | AR | 2020 | 29.5 | 22.0 | 40 | 20.9 | 4540 | 352 | .0775 | 735 | 11000 | 22.0 | 1430 | 1646 | 1356 | 21.7 | .8 | 3730 | 285 | 243 |
| 7 | ----- | 11 | 147 | AL | 2020 | 24.6 | 19.3 | 33 | 17.3 | 3760 | 222 | .0590 | 595 | 7200 | 31.0 | 1640 | 1777 | 1437 | 18.8 | .6 | 3660 | 282 | 234 |
| 8 | ----- | 9 | 146 | AL | 2020 | 20.6 | 17.6 | 35 | 14.3 | 3070 | 175 | .0570 | 475 | 2300 | 76.0 | 2420 | 1699 | 1359 | 16.7 | .6 | 3680 | 256 | 214 |
| 9 | ----- | 9 | 143 | AL | 1830 | 20.2 | 16.8 | 32 | 14.7 | 2900 | 165 | .0569 | 430 | 2100 | 76.0 | 2210 | 1624 | 1294 | 16.5 | .4 | 3650 | 242 | 199 |
| 10 | ----- | 9 | 151 | AR | 1830 | 31.5 | 23.1 | 42 | 23.6 | 4570 | 355 | .0777 | 730 | 12800 | 10.8 | 870 | 1699 | 1384 | 22.8 | .6 | 3720 | 284 | 241 |
| 11 | ----- | 9 | 146 | AL | 1830 | 24.5 | 19.1 | 28 | 18.1 | 3420 | 196 | .0573 | 545 | 7800 | 25.0 | 1200 | 1725 | 1400 | 18.8 | .4 | 3600 | 272 | 223 |
| 12 | ----- | 9 | 144 | AL | 1830 | 22.7 | 18.1 | 27 | 16.6 | 3180 | 181 | .0569 | 495 | 5900 | 33.0 | 1480 | 1699 | 1374 | 17.8 | .4 | 3590 | 266 | 217 |
| 13 | ----- | 9 | 145 | AR | 1720 | 30.5 | 22.6 | 42 | 23.6 | 4050 | 285 | .0704 | 665 | 12600 | 3.0 | 430 | 1672 | 1362 | 22.4 | .4 | 3580 | 282 | 230 |
| 14 | ----- | 9 | 147 | AL | 1720 | 25.5 | 19.6 | 32 | 19.6 | 3390 | 194 | .0573 | 550 | 9000 | 15.4 | 840 | 1698 | 1393 | 19.4 | .4 | 3600 | 271 | 222 |
| 15 | ----- | 9 | 147 | AL | 1720 | 22.4 | 17.7 | 28 | 17.2 | 2990 | 170 | .0569 | 465 | 6000 | 28.0 | 1230 | 1643 | 1338 | 17.9 | .3 | 3610 | 255 | 209 |
| 16 | ----- | 9 | 146 | AL | 1720 | 20.0 | 16.6 | 31 | 15.2 | 2670 | 155 | .0581 | 410 | 2000 | 76.0 | 2120 | 1594 | 1289 | 16.4 | .5 | 3660 | 234 | 193 |
| 17 | ----- | 9 | 145 | AL | 1630 | 19.7 | 16.6 | 31 | 15.3 | 2410 | 145 | .0602 | 385 | 1600 | 76.0 | 1980 | 1546 | 1211 | 16.3 | .4 | 3700 | 221 | 183 |
| 18 | ----- | 9 | 149 | AL | 1630 | 28.7 | 21.6 | 36 | 22.6 | 3530 | 207 | .0578 | 600 | 10700 | 0 | 255 | 1675 | 1355 | 21.2 | .7 | 3650 | 274 | 228 |
| 19 | ----- | 9 | 149 | AL | 1630 | 25.6 | 19.6 | 29 | 20.0 | 3230 | 184 | .0570 | 530 | 9300 | 7.5 | 560 | 1623 | 1293 | 19.4 | .6 | 3700 | 257 | 216 |
| 20 | ----- | 9 | 150 | AL | 1630 | 23.9 | 18.6 | 31 | 18.6 | 2980 | 169 | .0567 | 485 | 7700 | 16.0 | 755 | 1594 | 1259 | 18.5 | .5 | 3730 | 245 | 207 |
| 21 | ----- | 9 | 146 | AL | 1530 | 19.6 | 16.1 | 30 | 15.6 | 2240 | 138 | .0616 | 365 | 1500 | 76.0 | 1875 | 1519 | 1159 | 16.1 | .4 | 3760 | 205 | 173 |
| 22 | ----- | 9 | 145 | AL | 1535 | 25.1 | 19.6 | 30 | 20.5 | 3020 | 171 | .0568 | 480 | 9300 | 0 | 260 | 1593 | 1238 | 19.4 | .4 | 3660 | 238 | 197 |
| 23 | ----- | 9 | 145 | AL | 1530 | 23.7 | 18.2 | 28 | 18.8 | 2760 | 159 | .0572 | 455 | 7800 | 7.5 | 520 | 1566 | 1246 | 18.5 | .3 | 3640 | 233 | 238 |
| 24 | ----- | 8 | 144 | AL | 1540 | 21.1 | 17.6 | 25 | 16.7 | 2410 | 145 | .0602 | 395 | 4500 | 27.0 | 1015 | 1540 | 1180 | 17.0 | .5 | 3680 | 210 | 174 |
| 25 | ----- | 8 | 142 | AL | 1430 | 19.0 | 16.1 | 28 | 15.6 | 2030 | 130 | .0640 | 325 | 1100 | 76.0 | 1355 | 1463 | 1123 | 16.1 | .3 | 3730 | 190 | 158 |
| 26 | ----- | 8 | 145 | AL | 1430 | 22.9 | 18.1 | 27 | 18.9 | 2460 | 146 | .0594 | 405 | 7500 | 0 | 0 | 1490 | 1145 | 18.3 | .3 | 3740 | 205 | 167 |
| 27 | ----- | 8 | 148 | AL | 1430 | 21.0 | 17.6 | 28 | 17.3 | 2250 | 139 | .0618 | 360 | 5300 | 17.5 | 675 | 1463 | 1118 | 17.1 | .4 | 3770 | 202 | 170 |
| 28 | ----- | 8 | 149 | AL | 1430 | 19.9 | 16.8 | 26 | 16.4 | 2130 | 134 | .0629 | 340 | 3200 | 33.0 | 1100 | 1463 | 1123 | 16.5 | .4 | 3870 | 179 | 126 |
| 24,000 feet altitude flight | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 23650 | -21 | 149 | AR | 2330 | 15.9 | 13.3 | 10 | 10.1 | 2920 | 217 | 0.0743 | 370 | 2600 | 75.0 | 2350 | 1528 | 1280 | 13.0 | 0.6 | 3370 | 206 | 178 |
| 2 | 23700 | -20 | 155 | AR | 2330 | 37.9 | 28.0 | 51 | 24.6 | 6750 | 583 | .0864 | 975 | 18100 | 23.0 | 2475 | 1635 | ---- | 27.3 | 1.0 | 3310 | 316 | 263 |
| 3 | 23600 | -21 | 144 | AR | 2330 | 30.6 | 22.8 | 36 | 20.0 | 5450 | 467 | .0857 | 790 | 15300 | 25.5 | 2030 | 1637 | ---- | 22.2 | .8 | 3130 | 300 | 236 |
| 4 | 23650 | -21 | 145 | AR | 2330 | 23.4 | 17.8 | 22 | 15.0 | 4800 | 405 | .0844 | 590 | 11000 | 31.4 | 1800 | 1681 | 1400 | 17.0 | .8 | 3150 | 288 | 229 |
| 5 | 23650 | -21 | 152 | AR | 2020 | 32.0 | 23.0 | 37 | 22.6 | 4890 | 414 | .0846 | 805 | 16300 | 15.0 | 1290 | 1660 | 1350 | 22.6 | .9 | 3280 | 292 | 241 |
| 6 | 23650 | -22 | 151 | AR | 2040 | 27.7 | 19.8 | 27 | 19.8 | 4350 | 359 | .0825 | 680 | 14000 | 18.0 | 1170 | 1687 | 1300 | 19.4 | 1.0 | 3220 | 288 | 235 |
| 7 | 23600 | -21 | 142 | AL | 2030 | 20.7 | 15.8 | 14 | 14.6 | 3290 | 228 | .0693 | 485 | 9100 | 27.0 | 1100 | 1756 | 1400 | 15.4 | .7 | 3070 | 270 | 210 |
| 8 | 23550 | -21 | 141 | AL | 2040 | 15.6 | 13.4 | 12 | 11.0 | 2450 | 175 | .0714 | 340 | 2200 | 76.0 | 1990 | 1578 | 1220 | 12.7 | .5 | 3190 | 220 | 179 |
| 9 | 23550 | -22 | 142 | AL | 1830 | 15.2 | 13.1 | 7 | 11.5 | 2210 | 162 | .0733 | 315 | 2000 | 76.0 | 1790 | 1506 | 1210 | 12.6 | .6 | 3270 | 186 | 156 |
| 10 | 23650 | -21 | 150 | AR | 1840 | 31.0 | 22.8 | 31 | 22.9 | 4550 | 380 | .0835 | 725 | 16200 | 7.6 | 780 | 1667 | 1300 | 12.1 | .8 | 3190 | 286 | 230 |
| 11 | 23600 | -22 | 152 | AL | 1840 | 25.9 | 19.0 | 21 | 19.3 | 3760 | 258 | .0686 | 600 | 13700 | 11.9 | 740 | 1753 | 1450 | 18.2 | .9 | 3280 | 280 | 233 |
| 12 | 23600 | -22 | 149 | AL | 1840 | 20.5 | 15.8 | 9 | 15.1 | 2980 | 207 | .0695 | 460 | 9200 | 21.5 | 920 | 1662 | 1300 | 15.1 | .7 | 3230 | 244 | 206 |
| 13 | 23550 | -22 | 142 | AL | 1710 | 15.0 | 12.9 | 5 | 11.6 | 2050 | 155 | .0756 | 300 | 1800 | 76.0 | 1725 | 1480 | 1100 | 12.6 | .3 | 3210 | 196 | 162 |
| 14 | 23600 | -21 | 150 | AR | 1710 | 31.0 | 22.8 | 32 | 23.8 | 4140 | 338 | .0817 | 685 | 16800 | 0 | 385 | 1723 | 1250 | 22.2 | .5 | 3190 | 285 | 230 |
| 15 | 23600 | -21 | 148 | AL | 1710 | 23.5 | 17.8 | 18 | 17.8 | 3170 | 220 | .0694 | 510 | 12300 | 6.0 | 480 | 1690 | 1350 | 17.0 | .6 | 3170 | 260 | 209 |
| 16 | 23600 | -19 | 150 | AL | 1750 | 15.0 | 12.0 | 17 | 11.3 | 2010 | 152 | .0756 | 310 | 2400 | 76.0 | 1720 | 1480 | 1060 | 12.4 | .3 | 3320 | 187 | --- |
| 17 | 23600 | -20 | 149 | AR | 1740 | 29.4 | 20.9 | 31 | 22.4 | 4040 | 326 | .0807 | 660 | 16600 | 0 | 1220 | 1731 | 1360 | 21.1 | .8 | 3090 | 290 | 225 |
| 18 | 23600 | -20 | 150 | AL | 1735 | 23.7 | 17.1 | 12 | 18.1 | 3200 | 222 | .0694 | 520 | 13100 | 7.5 | 1220 | 1600 | 1310 | 16.8 | .9 | 3200 | 264 | 213 |
| 19 | 23550 | -19 | 150 | AL | 1730 | 17.0 | 13.2 | 17 | 12.7 | 2250 | 164 | .0729 | 355 | 6600 | 30.0 | 1040 | 1497 | 1200 | 13.1 | .5 | 3250 | 224 | 184 |
| 20 | 23750 | -17 | 148 | AL | 1630 | 23.0 | 16.7 | 6 | 17.9 | 2940 | 205 | .0697 | 480 | 14700 | 0 | 1150 | 1619 | 1320 | 16.7 | .8 | 3170 | 251 | 198 |
| 21 | 23550 | -16 | 151 | AL | 1630 | 19.0 | 14.2 | -5 | 14.9 | 2510 | 179 | .0713 | 390 | 9500 | 12 | 1010 | 1580 | 1360 | 13.6 | .4 | ---- | --- | --- |
| 22 | 23600 | -17 | 150 | AL | 1630 | 15.9 | 12.8 | -15 | 12.2 | 2030 | 153 | .0754 | 305 | 5000 | 76 | 1085 | 1466 | 1150 | 12.7 | .4 | 3340 | 182 | 153 |
| 23 | 23600 | -16 | 150 | AL | 1630 | 14.5 | ---- | -6 | ---- | ---- | --- | ------ | 280 | 2600 | ---- | 1440 | 1424 | 1100 | ---- | --- | ---- | --- | --- |
| 24 | 23550 | -16 | 149 | AL | 1540 | 19.8 | 15.0 | -6 | 15.9 | 2410 | 173 | .0718 | 380 | 9900 | 0 | 1185 | 1543 | 1190 | 15.0 | .3 | 3320 | 207 | 172 |
| 25 | 23500 | -17 | 149 | AL | 1530 | 18.0 | 14.1 | -15 | 14.6 | 2220 | 163 | .0734 | 350 | 8500 | 7.5 | 400 | 1463 | 1190 | 14.1 | .4 | 3420 | 198 | 170 |
| 26 | 23500 | -18 | 148 | AL | 1550 | 16.0 | 13.1 | -16 | 12.9 | 2170 | 161 | .0742 | 300 | 5000 | 26.0 | 780 | 1437 | 1150 | 12.9 | .5 | 3410 | 178 | 154 |
| 27 | 23550 | -18 | 150 | AL | 1550 | 14.6 | 12.2 | -17 | 11.9 | 1800 | 143 | .0794 | 270 | 2300 | 76.0 | 1560 | 1336 | 1060 | 12.1 | .5 | 3460 | 153 | 136 |
| 28 | 23650 | -19 | 150 | AL | 1450 | 17.8 | 14.0 | -18 | 14.6 | 2100 | 156 | .0743 | 315 | 8300 | 0 | 236 | 1433 | 1110 | 13.9 | .4 | 3440 | 173 | 152 |
| 29 | 23600 | -19 | 153 | AL | 1440 | 16.0 | 13.3 | -13 | 13.0 | 1860 | 145 | .0780 | 280 | 5700 | 19.0 | 555 | 1360 | 1100 | 12.8 | .5 | 3460 | 163 | 145 |
| 30 | 23650 | -19 | 150 | AL | 1460 | 14.4 | 12.6 | 16 | 11.8 | 1550 | 131 | .0845 | 245 | 2100 | 76.0 | 1530 | 1287 | 1000 | 12.0 | .3 | 3530 | 141 | 129 |


Figure 1. - Airplane used for the heat-exchanger tests.

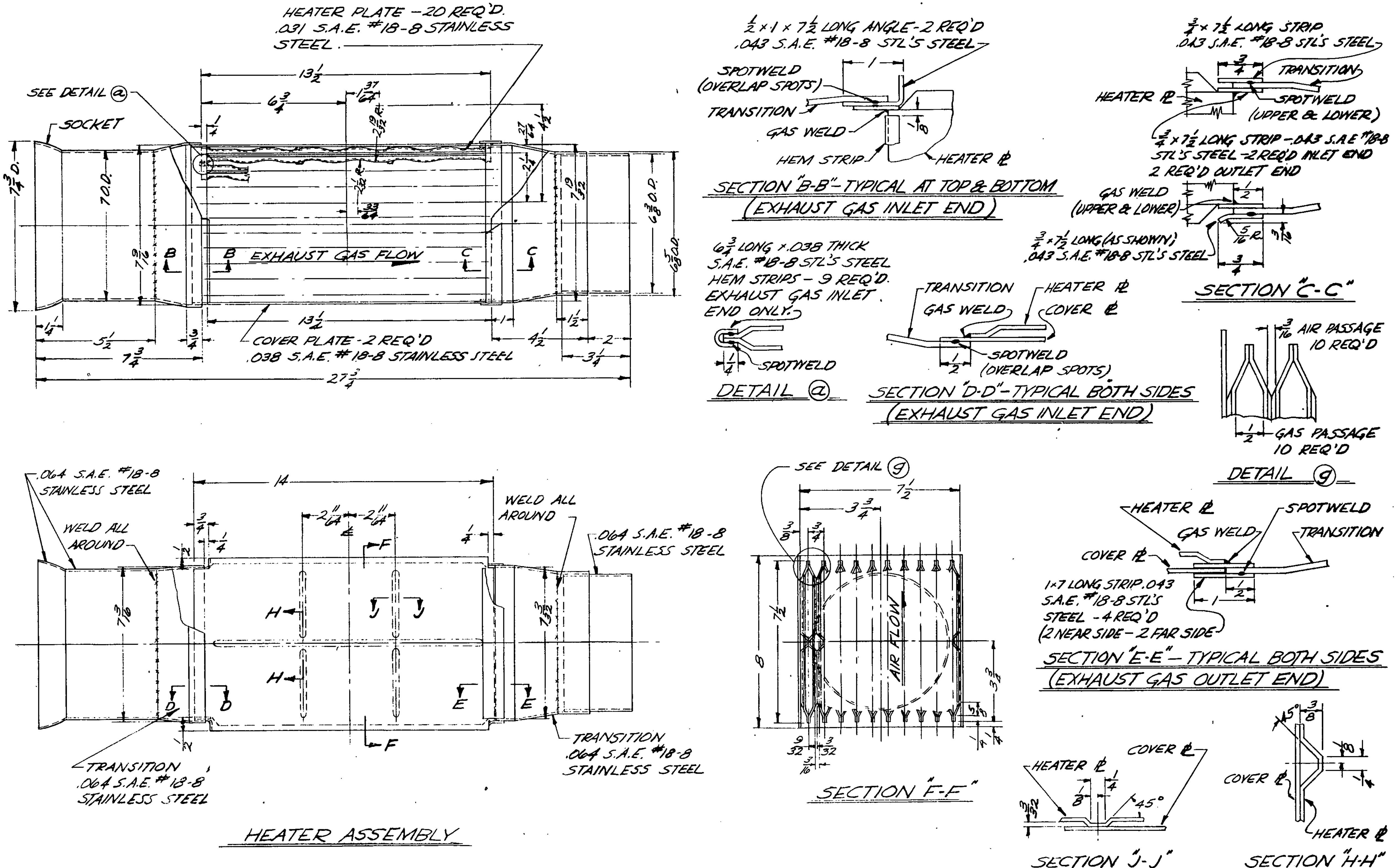


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FIGURE 2. - DETAILS OF THE HEAT EXCHANGER TESTED.

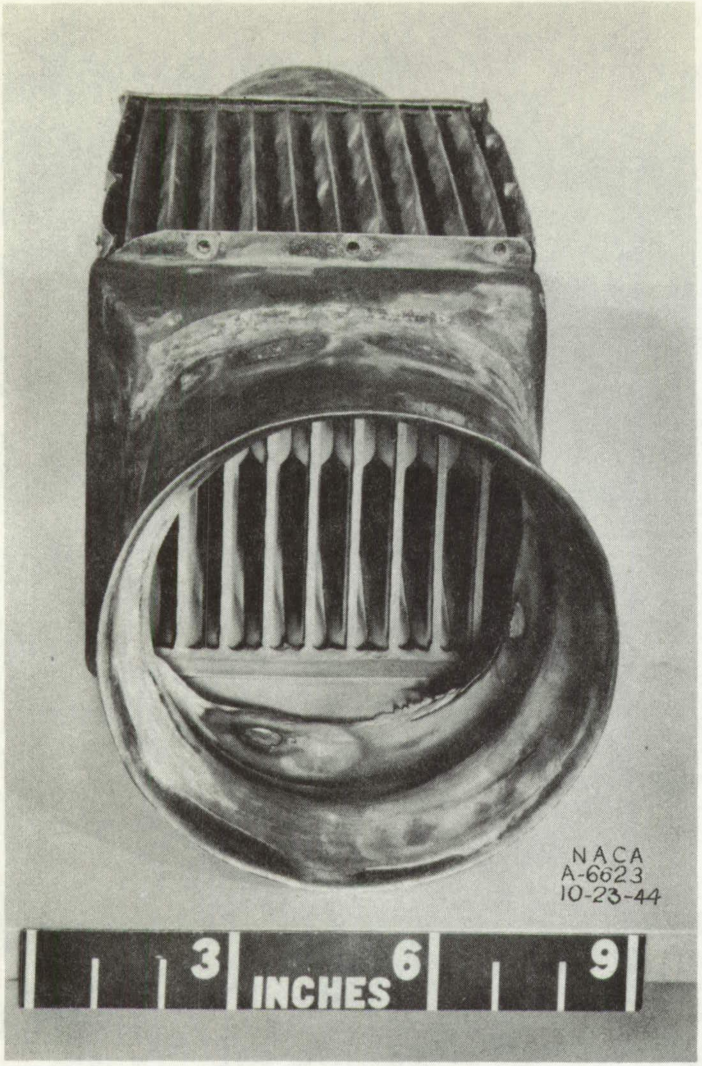


Figure 3. - End view of heat exchanger tested showing exhaust-gas passages.

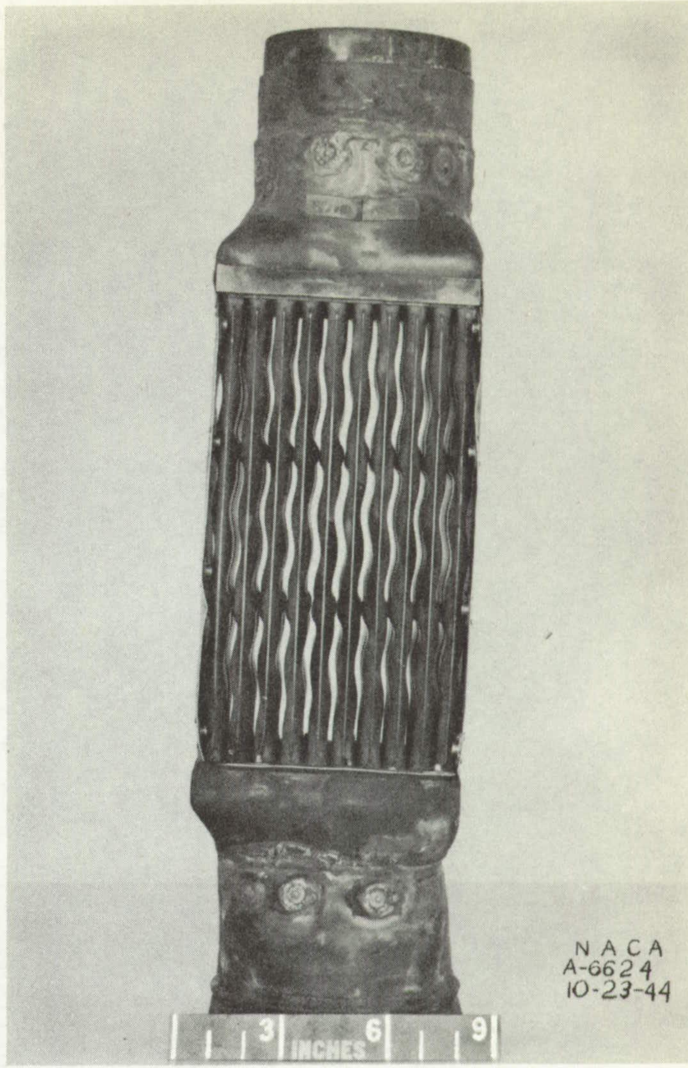


Figure 4. - Side view of heat exchanger tested showing air passages.

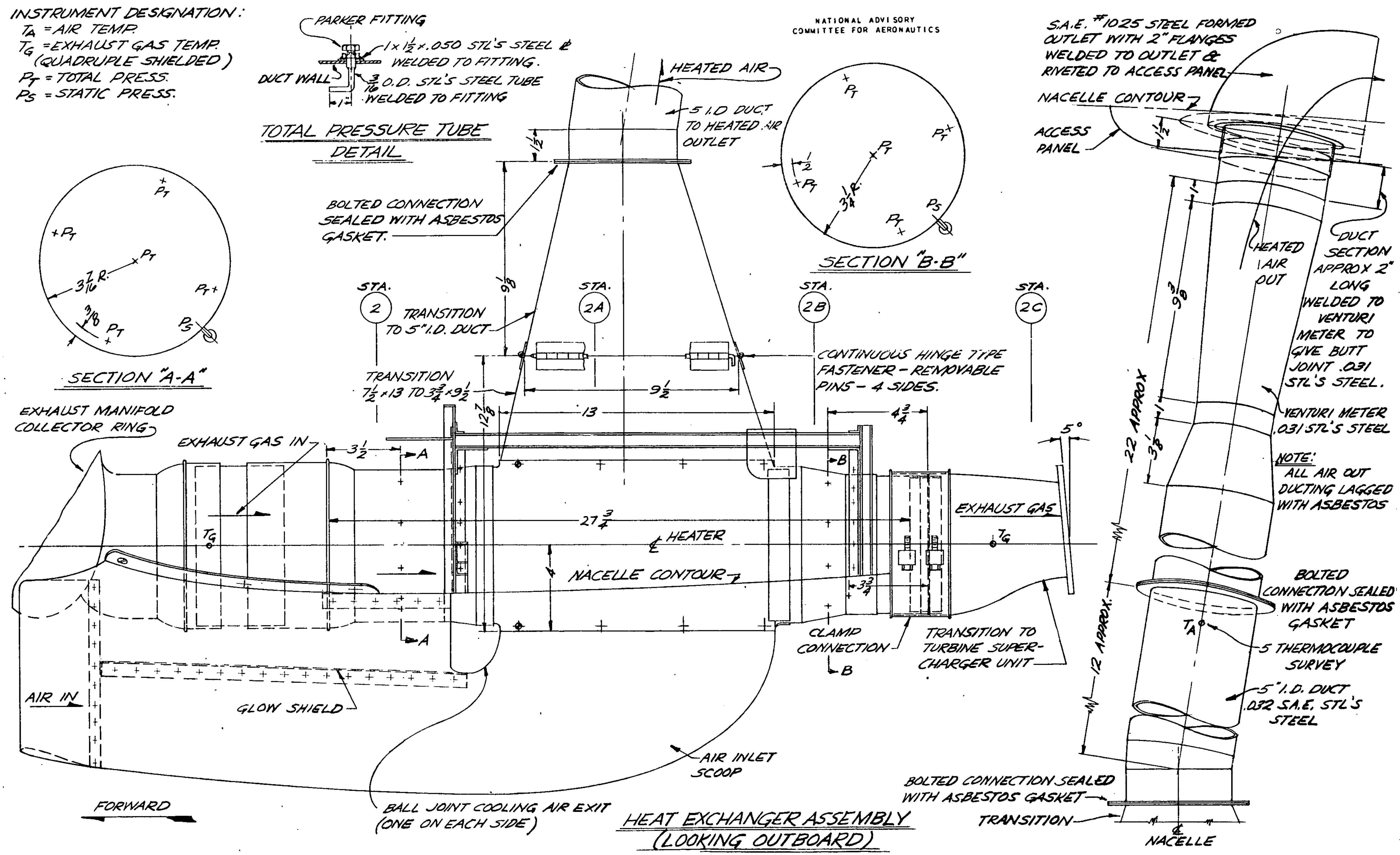


FIGURE 5. - SIDE VIEW OF HEAT-EXCHANGER INSTALLATION.

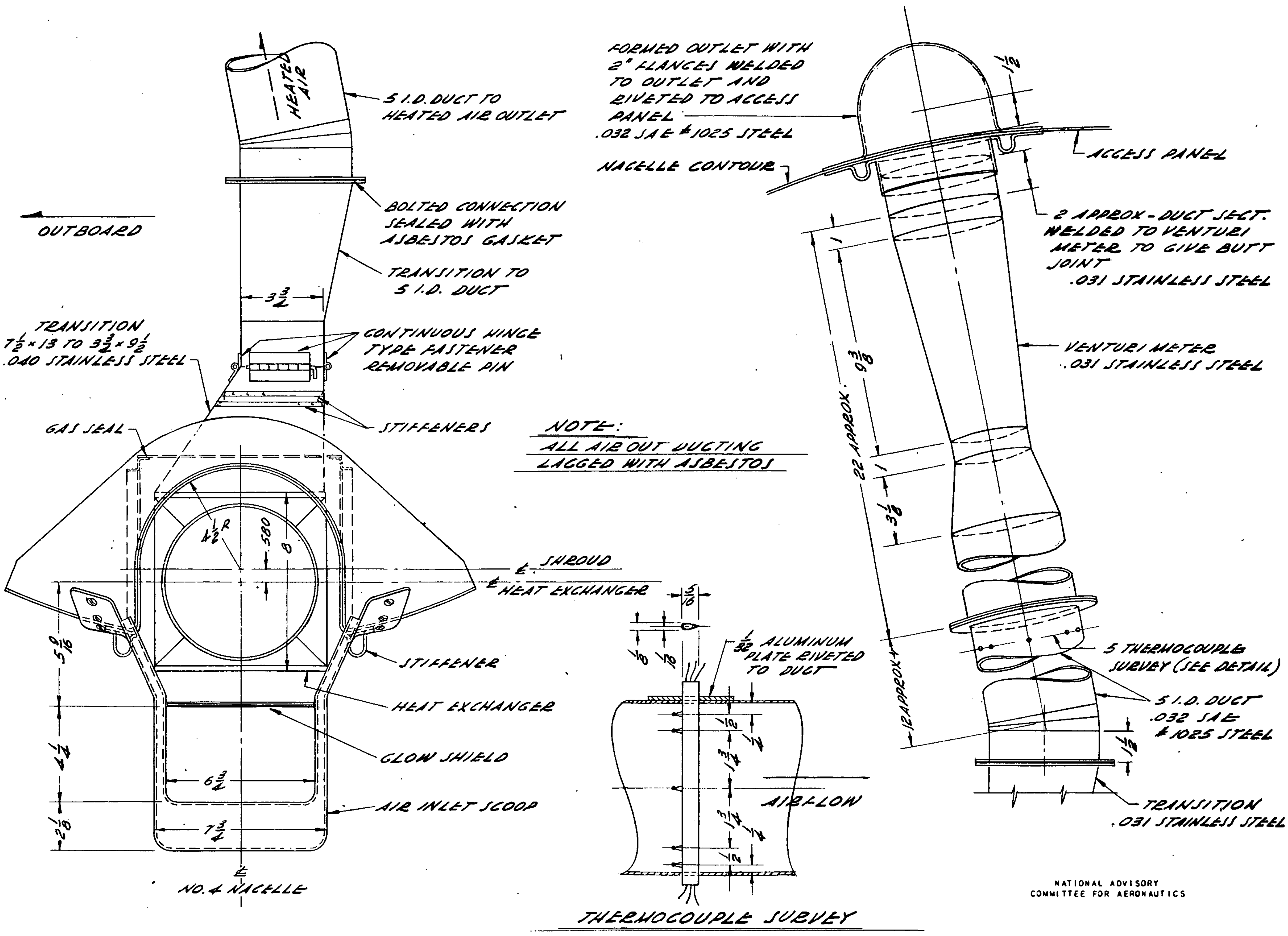


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FIGURE 6. - END VIEW OF HEAT-EXCHANGER INSTALLATION.

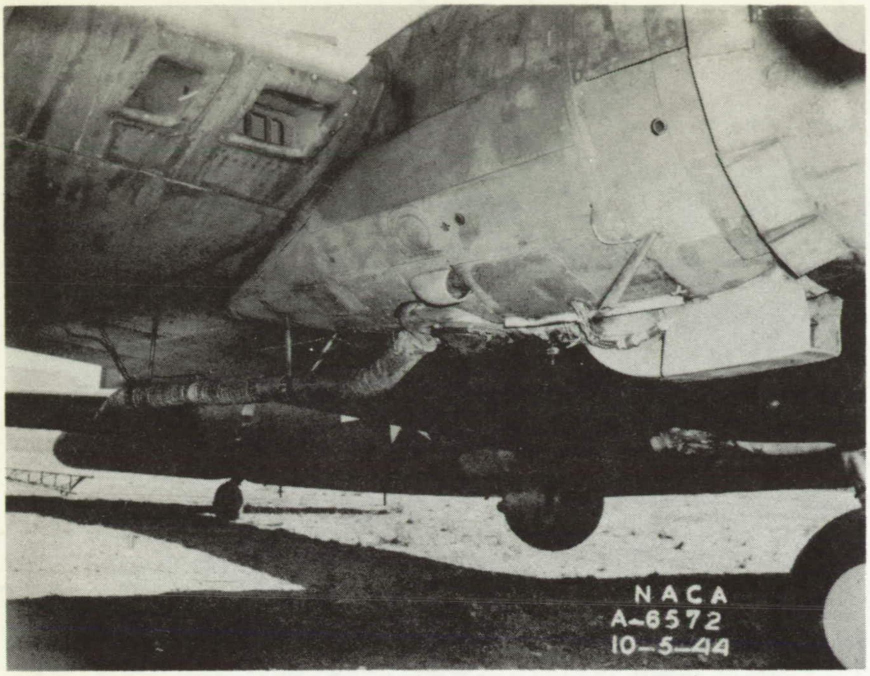


Figure 7. - The heat exchanger installed between exhaust collector ring and turbosupercharger and venturi meter installed in duct connected to turbosupercharger waste gate.

LEGEND:

W = FLOW RATE

H = TOTAL PRESSURE

P = STATIC PRESSURE

T = TEMPERATURE

SUBSCRIPTS:

a = ATMOSPHERIC AIR
c = CARBURETOR AIR
e = EXHAUST GAS
h = HEATED AIR FROM EXCHANGER
m = ENGINE MANIFOLD

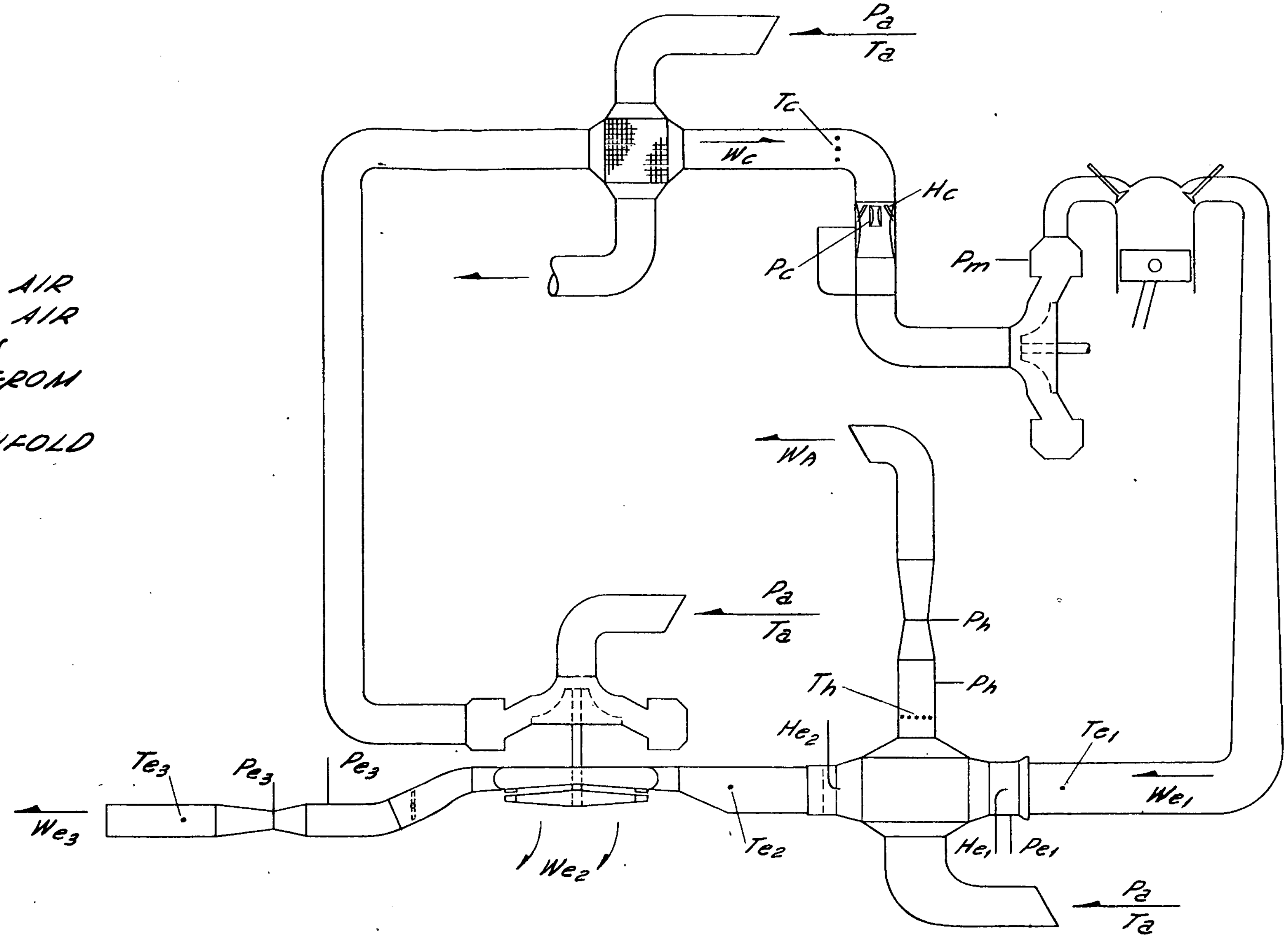


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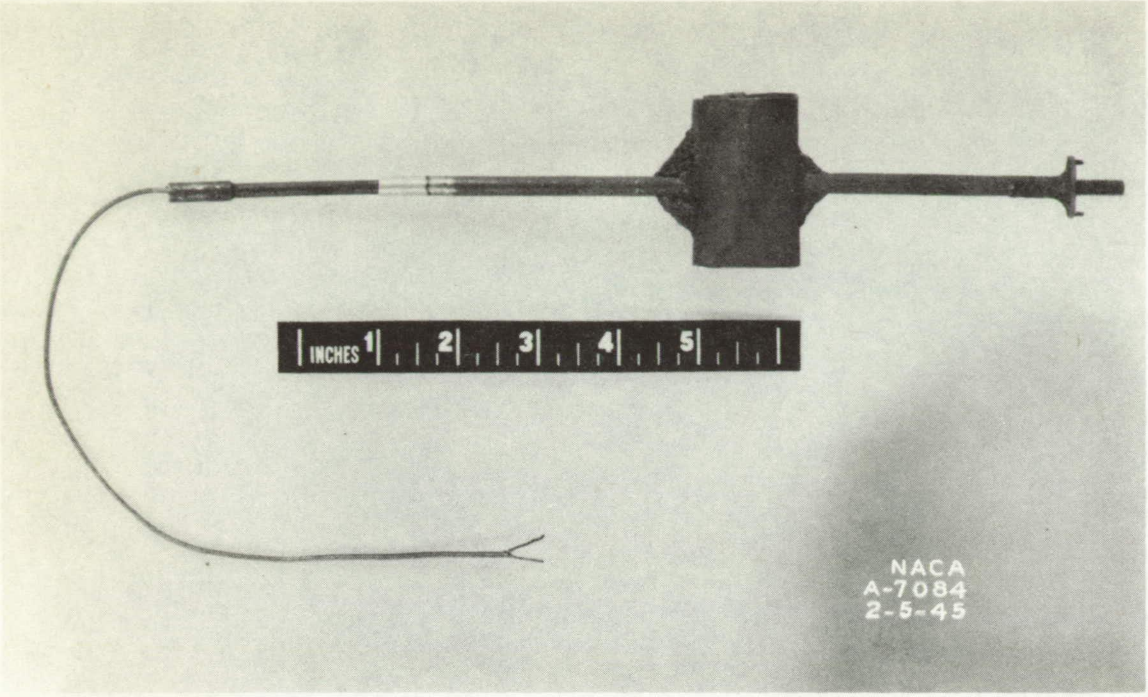
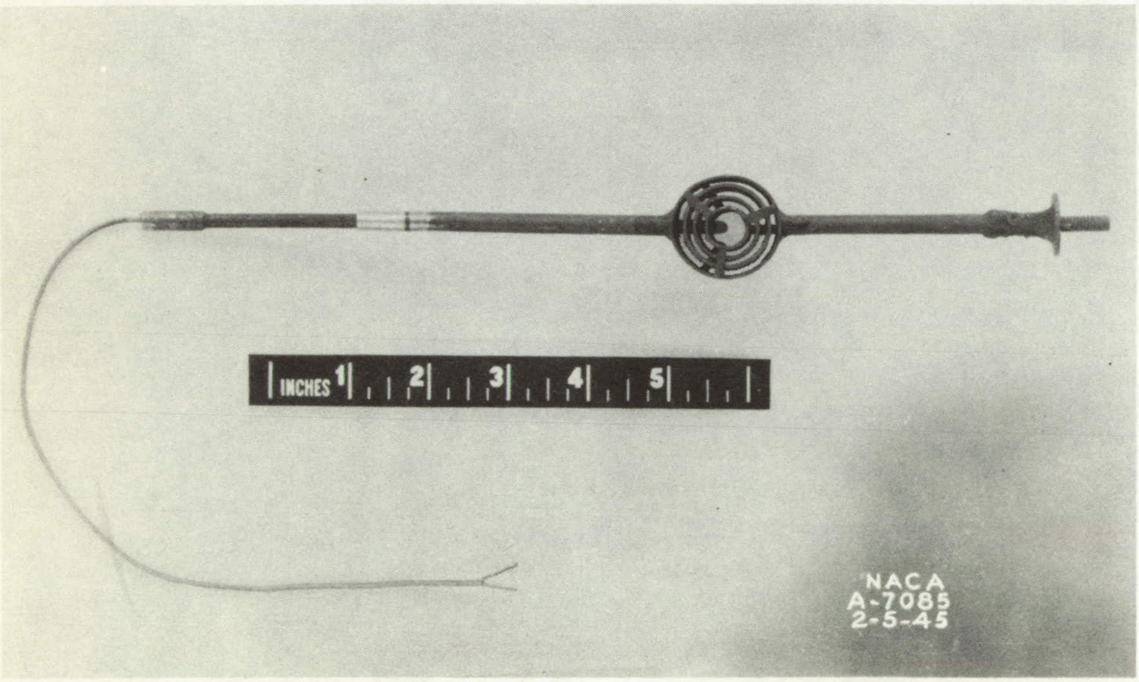
FIGURE 8. - SCHEMATIC DIAGRAM OF THE INDUCTION AND EXHAUST SYSTEMS WITH THE HEAT EXCHANGER INSTALLED.




(a) Side view.




(b) Front view.

Figure 9. - Type of quadruple-shielded thermocouple used to obtain exhaust-gas temperatures.

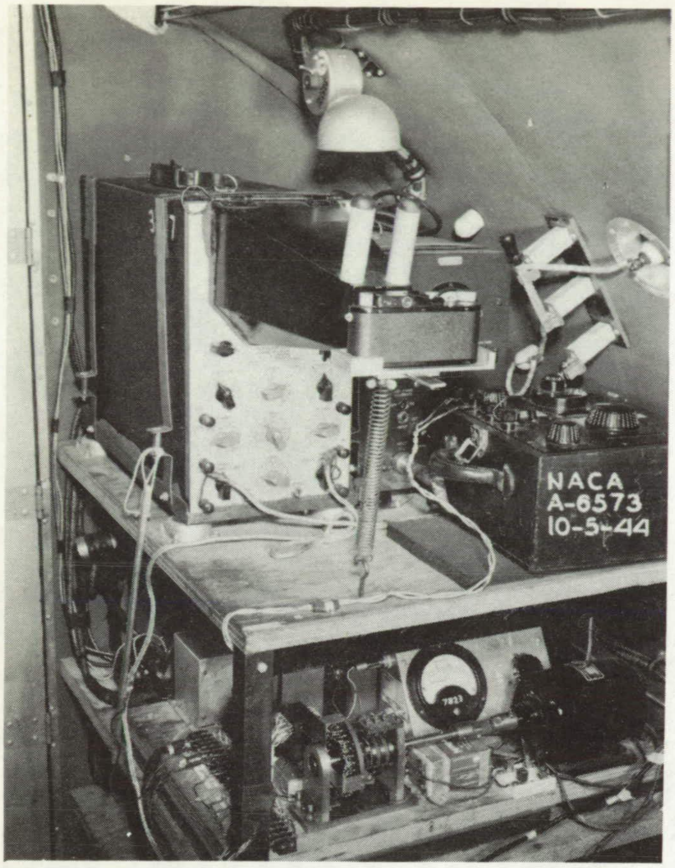



Figure 10. - Temperature-recording equipment installed in the test airplane for the heat-exchanger tests

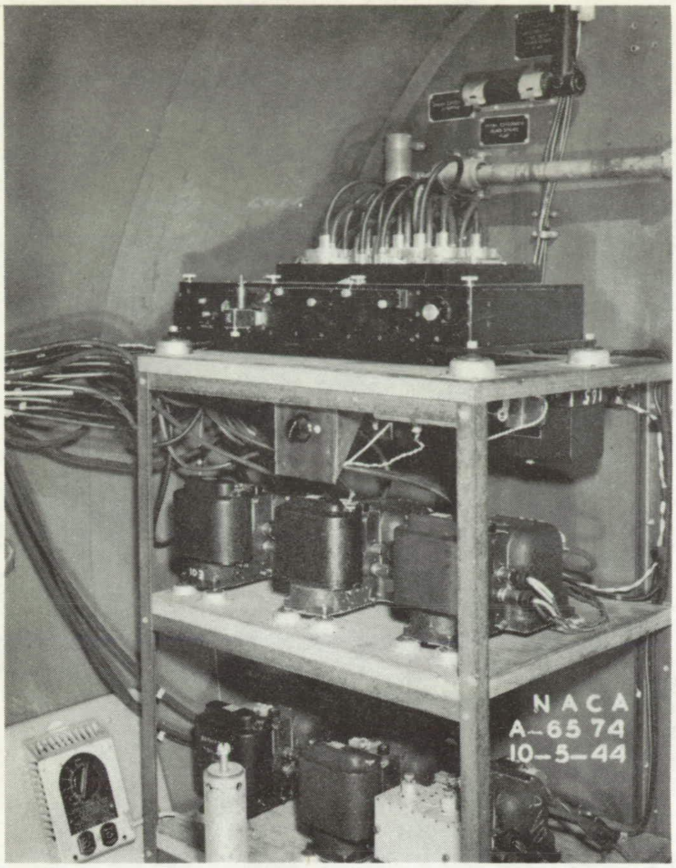



Figure 11. - Pressure and speed recording instruments installed in the test airplane for the heat-exchanger tests.

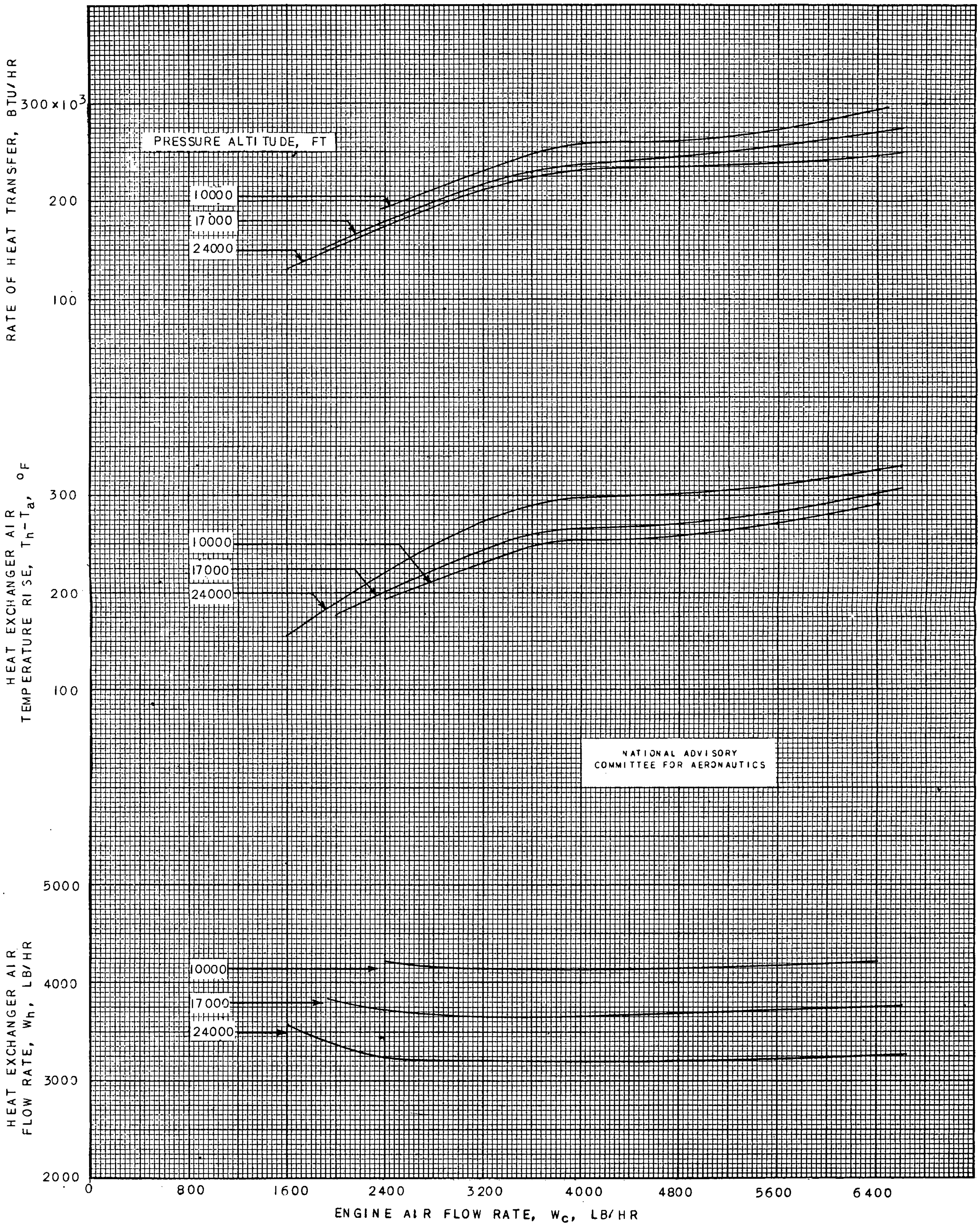



FIGURE 12. - VARIATION WITH ENGINE AIR-FLOW RATE OF HEAT-EXCHANGER AIR-FLOW RATE, AIR-TEMPERATURE RISE, AND RATE OF HEAT TRANSFER FOR HEAT EXCHANGER INSTALLED IN NACELLE 4 OF TEST AIRPLANE. ENGINE OPERATED AT FULL THROTTLE; POWER VARIED WITH TURBOSUPERCHARGER CONTROL; CONSTANT INDICATED AIRSPEED OF ABOUT 150 MPH MAINTAINED.

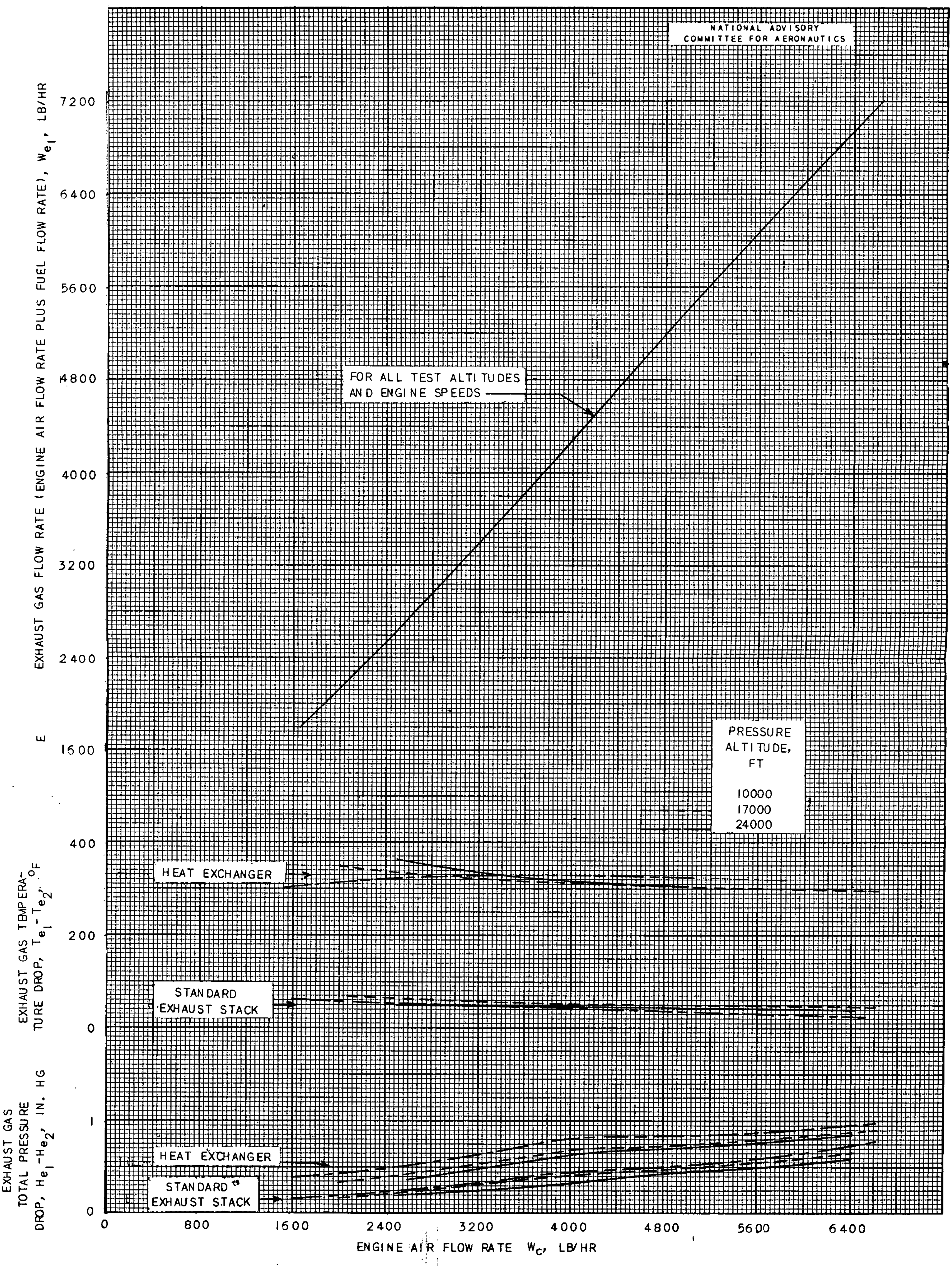



FIGURE 13. - VARIATION WITH ENGINE AIR-FLOW RATE OF EXHAUST-GAS-FLOW RATE AND GAS TEMPERATURE AND PRESSURE DROPS ACROSS THE HEAT EXCHANGER AND AN EQUAL LENGTH OF STANDARD EXHAUST STACK INSTALLED IN NACELLE 4 OF THE TEST AIRPLANE. ENGINE OPERATED AT FULL THROTTLE; POWER VARIED WITH TURBOSUPERCHARGER CONTROL; CONSTANT INDICATED AIRSPEED OF ABOUT 150 MPH MAINTAINED.

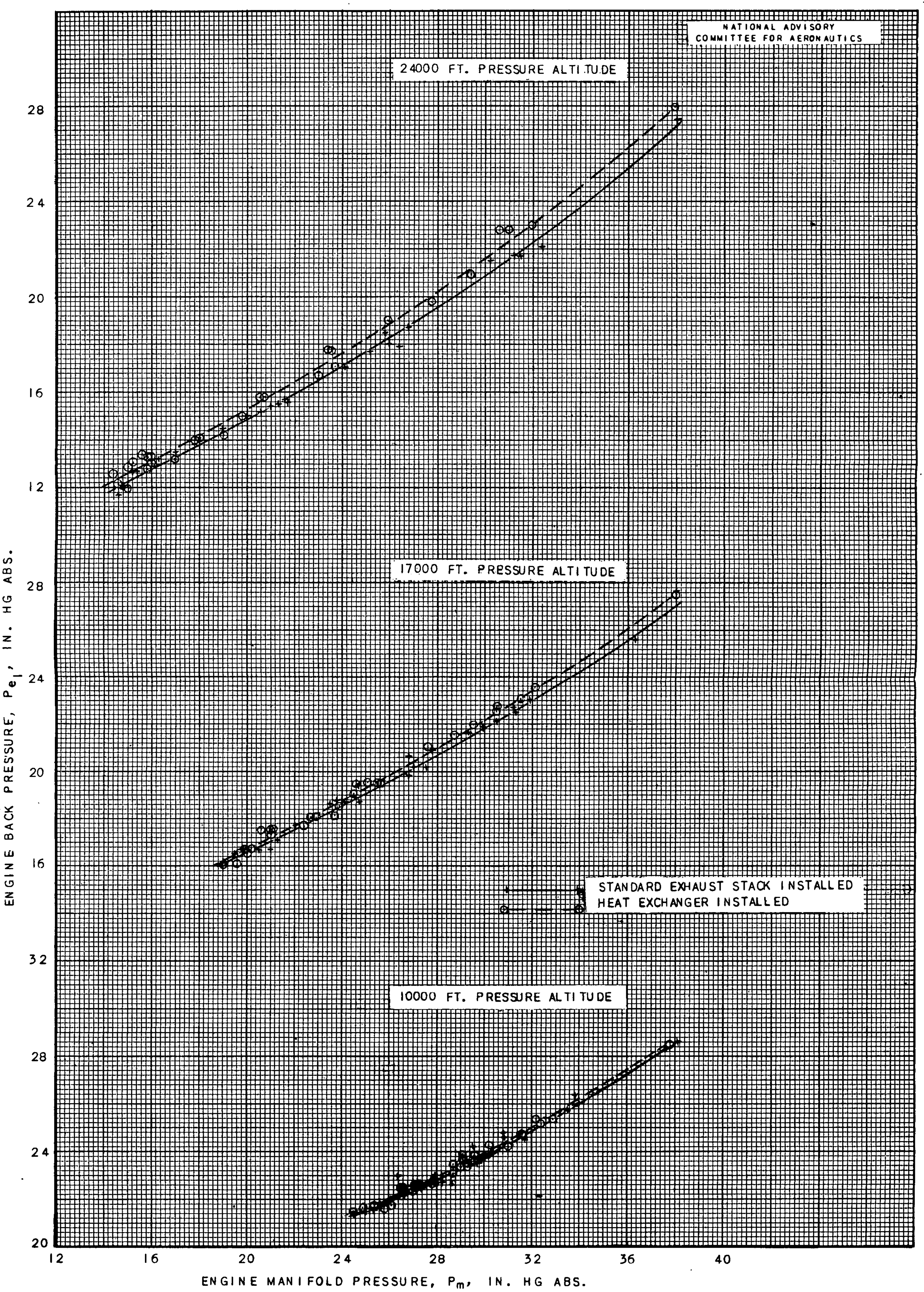



FIGURE 14. - RELATIONSHIP BETWEEN ENGINE 4 MANIFOLD AND BACK PRESSURES WITH AND WITHOUT A HEAT EXCHANGER INSTALLED IN NACELLE 4 OF THE TEST AIRPLANE. ENGINE OPERATED AT FULL THROTTLE; POWER VARIED WITH TURBOSUPERCHARGER CONTROL; CONSTANT INDICATED AIR-SPEED OF ABOUT 150 MPH MAINTAINED.

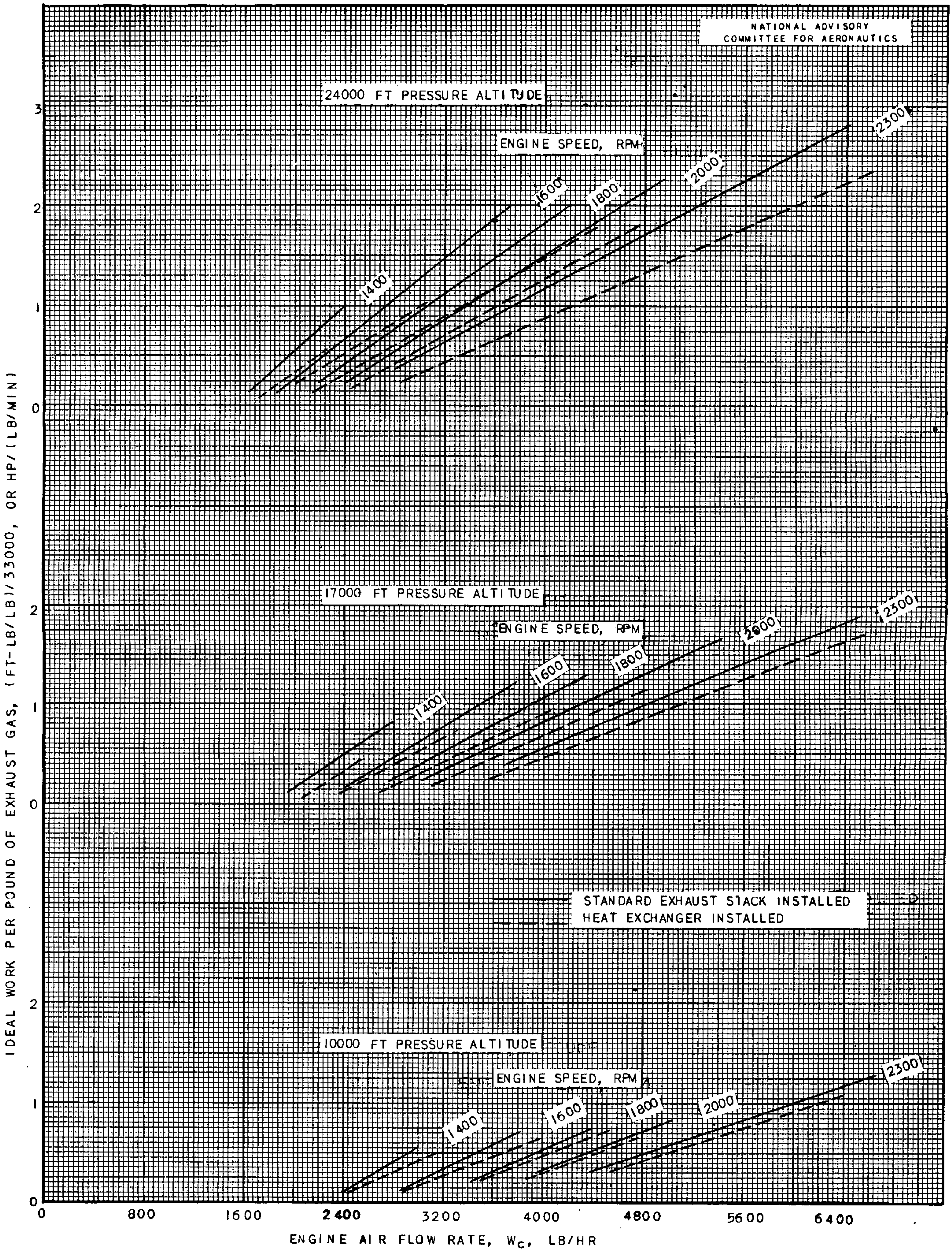



FIGURE 15. - VARIATION WITH ENGINE AIR-FLOW RATE OF IDEAL WORK OF EXPANSION PER POUND OF EXHAUST GAS, BASED ON THE MEASURED TEMPERATURE AND PRESSURE AT THE NOZZLE-BOX ENTRANCE, WITH AND WITHOUT A HEAT EXCHANGER INSTALLED IN NACELLE 4 OF THE TEST AIRPLANE. ENGINE OPERATED AT FULL THROTTLE; POWER VARIED WITH TURBOSUPERCHARGER CONTROL; CONSTANT INDICATED AIRSPEED OF ABOUT 150 MPH MAINTAINED.

E-30

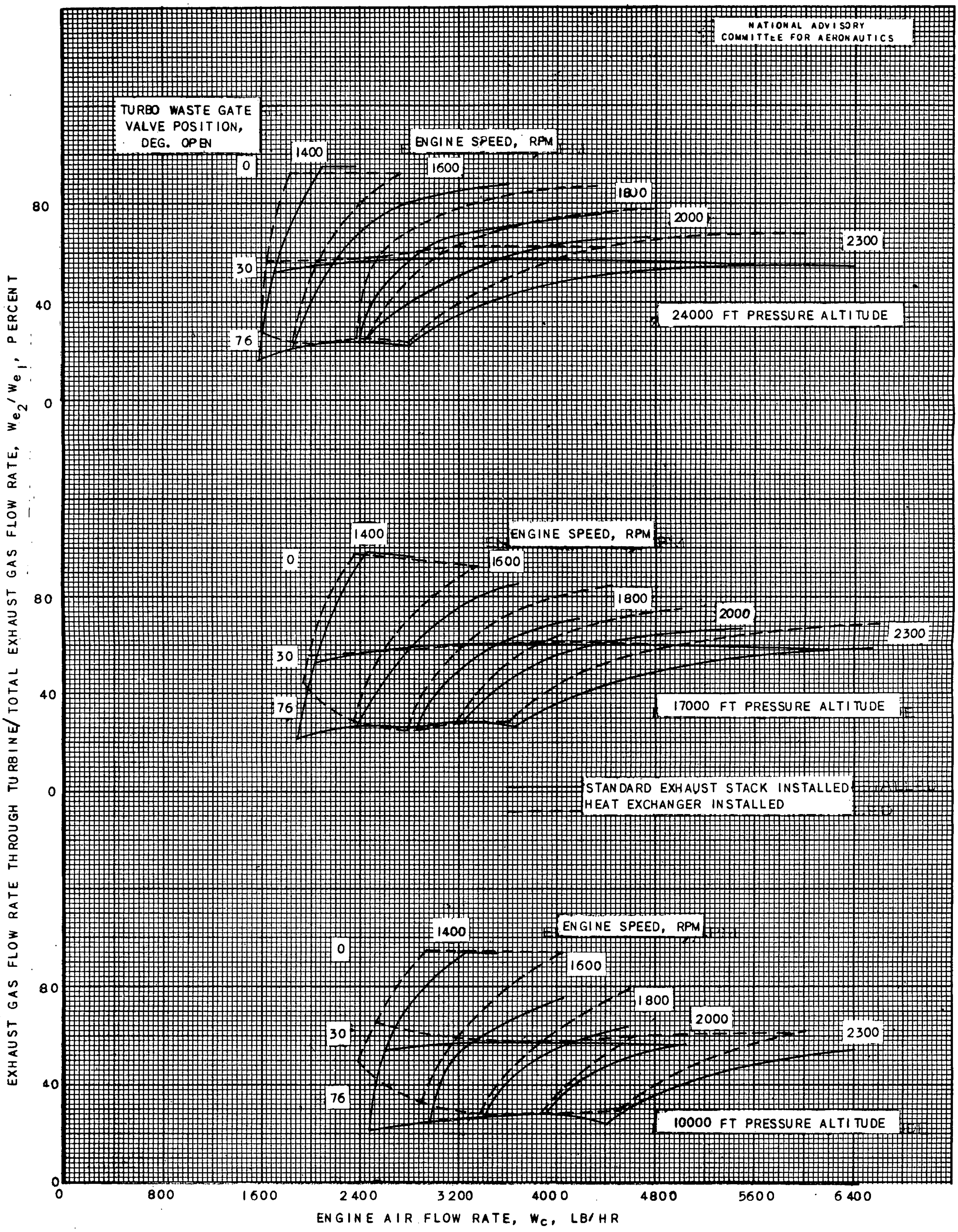



FIGURE 16. - VARIATION WITH ENGINE 4 AIR-FLOW RATE OF THE PERCENTAGE OF THE TOTAL EXHAUST GAS FLOWING THROUGH THE TURBINE WHEEL OF THE TURBOSUPERCHARGER WITH AND WITHOUT A HEAT EXCHANGER INSTALLED IN NACELLE 4 OF THE TEST AIRPLANE. ENGINE OPERATED AT FULL THROTTLE; POWER VARIED WITH TURBOSUPERCHARGER CONTROL; CONSTANT INDICATED AIRSPEED OF ABOUT 150 MPH MAINTAINED.

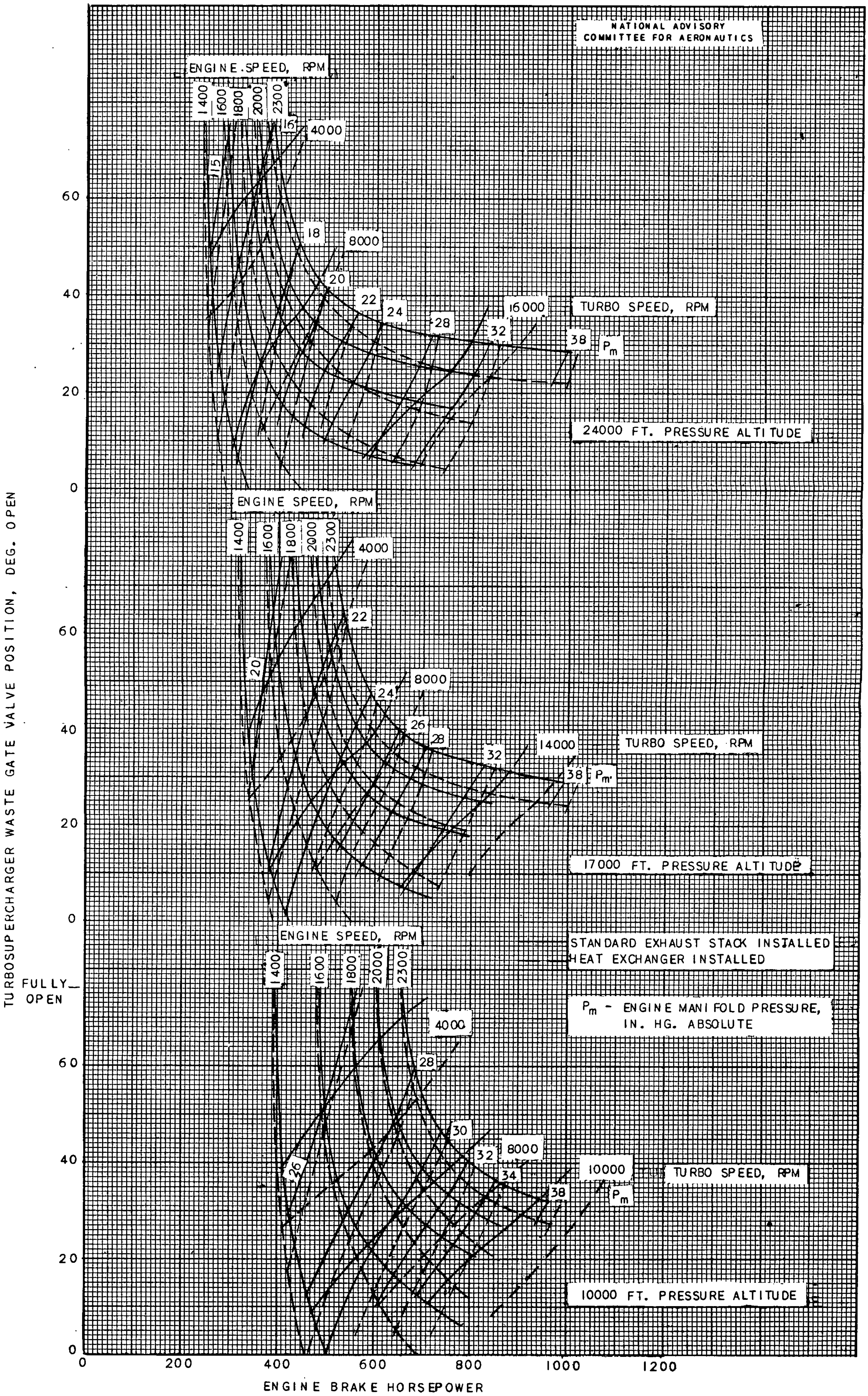



FIGURE 17. - ENGINE AND TURBOSUPERCHARGER OPERATION WITH AND WITHOUT A HEAT EXCHANGER INSTALLED IN NACELLE 4 OF THE TEST AIRPLANE. ENGINE OPERATED AT FULL THROTTLE; CONSTANT INDICATED AIRSPEED OF ABOUT 150 MPH MAINTAINED.

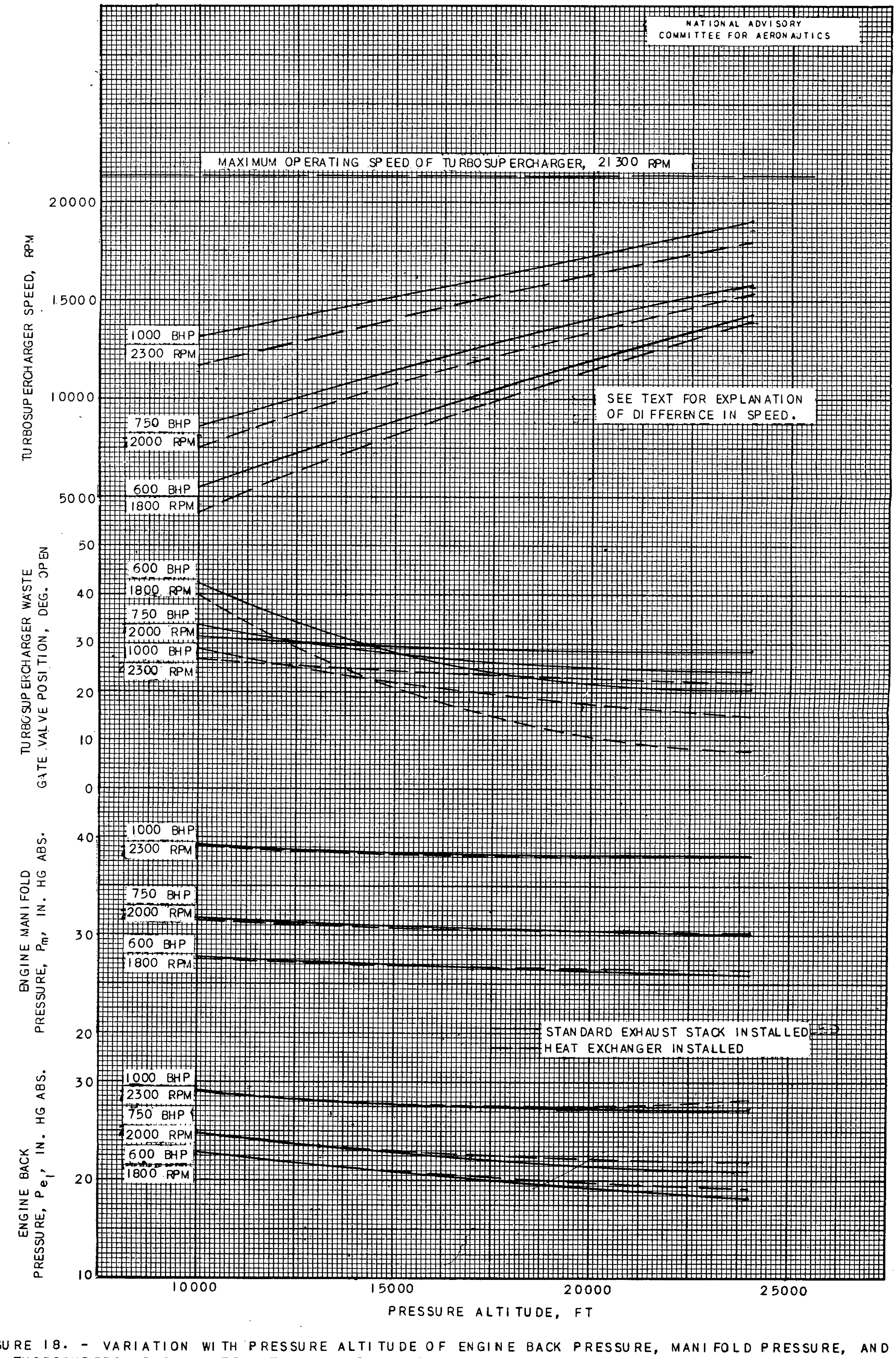



FIGURE 18. - VARIATION WITH PRESSURE ALTITUDE OF ENGINE BACK PRESSURE, MANIFOLD PRESSURE, AND TURBOSUPERCHARGER WASTE-GATE-VALVE POSITION AND SPEED FOR RATED, MAXIMUM CRUISE, AND NORMAL CRUISE POWERS WITH AND WITHOUT A HEAT EXCHANGER INSTALLED IN NACELLE 4 OF THE TEST AIRPLANE. ENGINE OPERATED AT FULL THROTTLE AND CONSTANT INDICATED AIRSPEED OF ABOUT 150 MPH MAINTAINED.